TR 63-7-858 VOLUME IV
OF VI VOLUMES

REINFORCED PLASTIC CONSTRUCTION METHODS FOR LARGE ROCKET MOTOR CASE

VOLUME IV TU-290 CASE DESIGN AND FABRICATION

FINAL TECHNICAL ENGINEERING REPORT
DECEMBER 1963

SUBMITTED TO

CHEMICAL PROCESSING BRANCH
MANUFACTURING TECHNOLOGY DIVISION
AIR FORCE MATERIALS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

PROJECT 7-858

PREPARED UNDER

CONTRACT AF 33(600)-42511

BY

THIOKOL CHEMICAL CORPORATION
WASATCH DIVISION
BRIGHAM CITY, UTAH

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TR 63-7-858 Volume IV
of VI Volumes

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REINFORCED PLASTIC CONSTRUCTION METHODS FOR LARGE ROCKET MOTOR CASE

VOLUME IV - TU-290 CASE DESIGN AND FABRICATION

W. G. Morse
F. W. Dallon

THIOKOL CHEMICAL CORPORATION
WASATCH DIVISION

Contract AF 33(600)-42511
ASD Project 7-858

ABSTRACT

From Thiokol specifications and drawings, case designs and fabrication processes were established for the TU-290 monolithic fiberglass case. Phase III program requirements specified development, by progressive improvement of case design following fabrication, hydroburst, and evaluation, of a single nozzle case; a case to have a motor mass fraction (excluding igniter) of 0.965, and which could withstand 400,000 psi hoop stress at a burst pressure of 792 psig. The first three (of five) cases were hydroburst to evaluate designs, materials, winding equipment, and fabrication techniques. These cases withstood 575, 660, and 750 psig, respectively. The results for case No. 3 (379,000 psi hoop stress at 750 psig) were considered to satisfy design aims and objectives (Supplemental Agreement No. 5, dated 6 June 1963). The remaining two cases, fabricated with insulation, successfully withstood hydroproof testing at 550 psig. For subsequent tests on these cases, motor and nozzle designs were prepared. A single, recessed, fixed, conical nozzle was fabricated and delivered to the Air Force for each of the two cases.

Chemical Processing Branch
Manufacturing Technology Division
Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

Publications No. 664-3315

FOREWORD

This Final Technical Documentary Report covers all work performed under Contract AF33(600)-42511 from 5 March 1961 to 15 November 1963. The manuscript was released by the author on 16 December 1963 for publication as an ASD Technical Engineering Report.

This contract with the Wasatch Division of Thiokol Chemical Corporation was initiated under Manufacturing Methods Project 7-858, "Reinforced Plastic Construction Methods for Large Rocket Motor Case". It was accomplished under the technical direction of Mr. Charles Tanis of the Chemical Processing Branch (MATC), Manufacturing Technology Division, AF Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

Mr. William G. Morse was the Program Manager. Mr. Morse was assisted by Mr. Frank Dallon as Program Manager. Those assisting in the program were Mr. C. J. North, Project Engineer, Mr. Vern Burton and Mr. Neil Visser, Contract Administrators, Mr. C. A. Thierry, Senior Buyer, Mr. Harold M. Lee, Manufacturing Engineer, and Mr. W. M. Horton, Test Engineer. Design and analysis effort was accomplished under Mr. C. R. Bratton and Mr. John Hinchman, with stress analyses on case and nozzle designs by Mr. W. D. Humphrey, Mr. Dale Abildskov, Mr. R. L. Webster, Mr. J. Daines, Mr. James L. Crandell, Mr. Alex Brinchman, Mr. Claire Williams, Mr. John Kapp, and Mr. John Wilson. Technical writing was completed by Mr. R. McKnight.

This project has been accomplished as a part of the Air Force Manufacturing Methods Program, the primary objective of which is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in economical production of USAF materials and components. The program encompasses the following technical areas:

Metallurgy - Rolling, Forging, Extruding, Casting, Fiber, Powder.
Chemical - Propellant, Coating, Ceramic, Graphite, Nonmetallics.
Electronic - Solid State, Materials and Special Techniques, Thermionics.
Fabrication - Forming, Material Removal, Joining, Components.

Suggestions concerning additional Manufacturing Methods development required on this or other subjects will be appreciated.

ABSTRACT

REINFORCED PLASTIC CONSTRUCTION METHODS FOR LARGE ROCKET MOTOR CASE (VOLUME IV TU-290 CASE DESIGN AND FABRICATION)

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PUBLICATION REVIEW

This volume has been reviewed and is approved.

FOR THE DIRECTOR:

Melvin E. Fields
MELVIN E. FIELDS
Colonel, USAF
Chief, Manufacturing Technology Division
AF Materials Laboratory

MASTER TABLE OF CONTENTS
REINFORCED PLASTIC CONSTRUCTION METHODS FINAL REPORT

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MASTER TABLE OF CONTENTS (Cont)
REINFORCED PLASTIC CONSTRUCTION METHODS FINAL REPORT

MASTER TABLE OF CONTENTS (Cont)
REINFORCED PLASTIC CONSTRUCTION METHODS FINAL REPORT

MASTER TABLE OF CONTENTS (Cont)
REINFORCED PLASTIC CONSTRUCTION METHODS FINAL REPORT

TABLE OF CONTENTS
VOLUME IV

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont)

LIST OF TABLES

VOLUME FOUR - TU-290 CASE DESIGN

I. INTRODUCTION

A. SCOPE OF VOLUME FOUR

The final report on the Reinforced Plastic Construction Methods for Large Rocket Motor Case Program, Contract AF 33(600)-42511, is presented in six volumes. Volume IV describes the design, fabrication, testing, and delivery of a 44 in. diameter, monolithic, fiberglass plastic case identified as TU-290. Stress analysis of the TU-290 case is given in Volume VI. The case mandrel is described in Volume V.

The work conducted to develop the TU-290 case was defined in Supplemental Agreement No. 4 to Contract AF 33(600)-42511, which was issued by the Air Force in August 1962. This agreement completely revised Phase III and deleted Phase IV of the original contract. The new Phase III delineated the design, fabrication, and hydroburst testing of three TU-290 cases and the fabrication, hydroproof testing, and delivery of two TU-290 cases (complete with insulation) and two nozzles to the Air Force.

Allison and Brunswick, whose existing tooling and facilities could be used for the TU-290 case with minimum modification, were considered as subcontractors for the five TU-290 cases. Allison was selected because of a demonstrated capability in developing the TU-227A case. The TU-227A case had a composite wall strength of 126,500 psi and glass stress of 300,000 psi, which were the highest values achieved in the industry at the time for a 44 in. diameter case produced with E-HTS glass.

B. DESIGN AND FABRICATION REQUIREMENTS

The purpose of the revised Phase III of the contract was to develop a single nozzle rocket motor case with an approximate diameter of 44 in., a hoop glass stress of 400,000 psi at burst, and a helical stress of 360,000 psi at burst. The case was designed to contain a PBAA type propellant with a resulting motor mass fraction of 0.965 (without the igniter).

At the close of the contract, Thiokol would deliver two cases and two nozzles to the Air Force.

To meet the design, fabrication, and delivery requirements of Phase III, three cases were to be built and tested to destruction. The contract was to proceed in the following manner.

1. TU-290 case No. 1 was to be a single nozzle design configuration fabricated of E-HTS glass without internal insulation. The case would be hydrostatically tested to destruction to establish the basic design for case No. 2.

2. TU-290 case No. 2 was to be constructed identically to case No. 1 except for the use of S-HTS glass, in place of E-HTS glass, as the case material. Following hydrostatic testing to destruction, test results would be compared to test results of case No. 1.

3. TU-290 case No. 3 was to be a resultant design of the first two cases. S-HTS glass would be used as the case material and the case would be hydrostatically tested to destruction. Design modifications, if any, would be incorporated into the fabrication of cases No. 4 and 5.

4. TU-290 cases No. 4 and 5 would be fabricated as dictated by the results of cases No. 1, 2, and 3. These two cases would include insulation, and would be hydroproof tested only before being delivered to the Air Force.

II. DISCUSSION

The preliminary design for the TU-290 case was prepared by Thiokol Chemical Corporation (Thiokol). This design was the foundation for developing the first two TU-290 cases. Design improvements obtained by developing, fabricating, and testing the first two cases were used to improve the design of case No. 3. The design improvements obtained by fabricating and testing case No. 3 were used to improve the final design for cases No. 4 and 5.

The design effort for the five TU-290 cases conducted by Thiokol and supported by Allison is presented below.

A. PROGRAM REQUIREMENTS

1. Design Considerations

a. Case

From the preliminary design for the TU-290 case by Thiokol, Allison established design details for a case compatible with winding equipment, tooling, facilities, and techniques at Allison.

The chief design considerations of this initial design effort were to provide a case with the following characteristics:

1. A monolithic, fiberglass filament wound case with a single, partially submerged nozzle whose motor mass fraction equalled or exceeded 0.965 (excluding motor igniter);
2. A case hoop glass stress of 400, 000 psi at burst;
3. A case helical glass stress of 360, 000 psi at burst;
4. The capability of successful rocket motor operation using a PBAA type propellant.

The case dimensions were an inside diameter of 44.10 in. and an overall length of 132.04 in. (tangent to tangent length of 102.84 in.). A single, fixed position partially recessed nozzle was selected to insure attainment of the 0.965 mass fraction. Utilizing a single nozzle, resulting in only one opening in each end, also simplified the case design and reduced the case fabrication time.

The preliminary case design is shown in Figure 1 and Table I. Detailed, theoretical stress analyses for the TU-290 case and nozzle are presented in Volume VI.

b. Winding Data

(1) Case--The case cylinder was designed for a helical winding pattern at a 21.5 deg helical angle. The 21.5 deg helical angle provided a constant stress at the fore and aft ports of the case and prevented the glass fibers from slipping after they were positioned on the mandrel.

Helical filaments, positioned on the mandrel, were covered by hoop filaments in the cylindrical section of the case. The helical windings carried the entire longitudinal load and part of the hoop load. The balance of the hoop load was carried by the hoop windings.

Case winding was accomplished using a double loop system of 12 spool, 12 end roving, a 0.963 in. helix band advance, and a 0.858 in. hoop band advance with a band width of 0.92 to 0.98 inches.

(2) Domes--The forward dome was wrapped with a polar or inplane pattern. Since the single polar opening corresponded to the 21.5 deg helical angle of the cylindrical section, the dome contour closely approximated the geodesic or isotensoid dome configuration. The contour was evaluated on an IBM 704 computer program to determine inner and outer contours, weight, enclosed volume, and principal stresses.

The aft dome was also wrapped with a polar pattern. Equations derived for the aft dome contour were basically the same as in the forward dome contour; the thinness of the dome wall permitted filament realignment under load to compensate for the slightly different loading on the aft dome. The single aft polar opening was basically similar to that of the forward dome.

(3) Skirts--The fiberglass skirt design of the TU-227A case was selected for the TU-290 case. The cylindrical design, of 80 percent helical and 20 percent hoop windings, permitted the skirt to be prefabricated, slipped on the case during the wrapping process, and secured in place by the hoop windings. After the case assembly was cured, 54 attachment bolt holes in the skirt were drilled and metal bushings were cemented in place to reduce bearing stresses on the fiberglass.

TABLE I

TU-290 MOTOR CASE CONFIGURATION

Nomenclature		
Geometry		
Length, tangent-to-tangent (in.)	102.844	
Diameter of glass wall, internal (in.)	44.160	
Helix angle (deg)	21.5	
Thickness, composite helical (in.)	0.040	
Thickness, composite hoop (in.)	0.058	
Thickness, case liner (in.)	0.060	
Skirt, forward and aft end		
Helix angle (deg)	21.5	
Thickness, maximum (in.)	0.125	
Pole pieces, forward and aft end		
ID (in.)	14.00	
Bolt circle (in.)	15.024	
Calculated Weight Summary (lb)		
Fiberglass laminate (helical)	64.9	
Fiberglass laminate (hoops)	63.6	
Liner	50.0	
Forward and aft skirts	20.0	
Forward and aft polar fittings	19.2	
Self-locking screw thread crescent insert	0.3	
Subtotal, filament wound case assembly after cure		218.0
PYROGEN cap	8.8	
Bolts	1.9	
Flat washers	0.1	
O-ring seal	0.1	
Self-locking screw thread crescent insert	0.1	
Total, filament wound case assembly, less nozzle and insulation		229.0

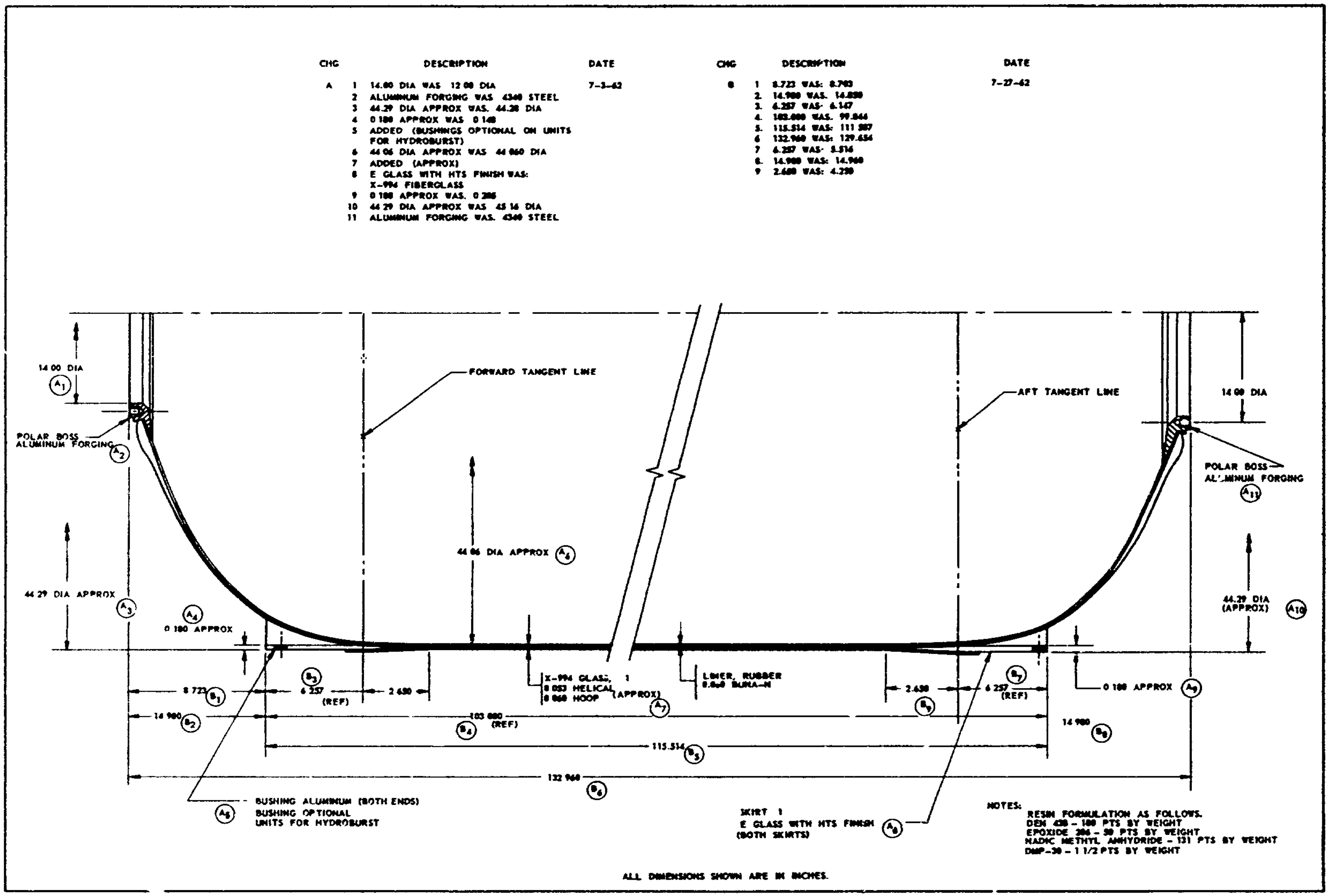

Figure 1. TU-290 Motor Case Specification Control Drawing

The forward and aft skirts were designed identically according to the following design considerations:

1. Single loop winding pattern;
2. Helical angle of 21.5 degrees;
3. Helical advance rate of 0.969 inch;
4. Hoop advance rate of 0.901 inch;
5. Band width of 0.950 inch.

c. Hardware Attachments

Forward and aft pole pieces of 7075-T6 aluminum were of the same basic design because the dome contours were similar. The geometry of the polar ring was determined by dome contours, imposed loads, and bonds between the ring and fiberglass at ultimate pressure.

The force required to tear the polar ring from the case opening depends upon the angle of interface between the polar ring and the fiberglass dome. (The force must always be nearly equal to the fiberglass restraining load while components are in the strained position.) Input was coded for computer solution to determine dimensions of the polar ring (Volume VI "Stress Analysis").

The recessed nozzle was bolted longitudinally to the aft polar ring. This arrangement permitted greater structural integrity, easier and quicker fabrication, and simpler handling.

2. Winding Equipment

The Allison winding machine for the TU-290 case was a lathe type unit with a headstock and a tailstock mounted on one machine bed. The guide carriage was mounted on another machine bed. The headstock, tailstock, and guide carriage all moved in linear directions.

The guide carriage moved the entire length of the machine bed on a path parallel to the mandrel centerline. A telescoping boom was mounted on the carriage and moved perpendicularly to the mandrel centerline. The boom could also be moved vertically. A filament guide was mounted on the end of the boom. Direct current servomotors provided power for all machine movements, and feedback devices monitored the winding movements.

An analog computer compared command and response signals to insure a winding pattern in accordance with case design. Properly related drive commands, generated as low power signals in a control center, controlled power equipment which executed the winding pattern.

3. Materials

a. Case

The case material was E-HTS reinforced fiberglass for case No. 1 and S-HTS glass for cases No. 2, 3, 4, and 5. The first case was a control unit used to identify design differences between the TU-227A case and the TU-290 case. The use of E-HTS glass provided an indication of the capability of S-HTS glass to meet case hoop glass stress (400, 000 psi) and case helical glass stress (360, 000 psi) requirements. (Laboratory tests showed an approximate 15 percent increase in strength of S-HTS over E-HTS glass.)

Both E-HTS and S-HTS glass bands were 12 spool, 12 end Owens-Corning material.

Physical characteristics of the two glass materials (based on an ultimate case pressure of 792 psig) are listed below.

	E-HTS	S-HTS
Ultimate tensile strength, case (σ_{ug}; psi)	350, 000	400, 000
Helical stress ($1.14\sigma_{ug}$-E; $0.90\sigma_{ug}$-S; psi)	400, 000	400, 000
Hoop stress ($1.03\sigma_{ug}$-E; $1.00\sigma_{ug}$-S; psi)	360, 000	360, 000
Ultimate tensile stress, strand (psi)	550, 000	600, 000
Filaments per end (number)	204	204
Filament diameter (in.)	0.00037	0.00037
Glass content nominal (yd/lb)	14, 000	15, 000

The resin system for the case wrapping material was the same for all five cases.

Resin	DEN 438 (Dow-epoxy-novalac) 100 pbw
	EPOXIDE 206 (Vinyl-ethyl-chloro-hexene dioxide) 50 pbw
Hardener	NMA (Nadic-methyl anhydride) 131 pbw
Catalyst	DMP-30 (Tri-dimethyl-amino-ethyl phenol) 1.5 pbw

The case liner for all five cases (as for the TU-227A case) was Gen-Gard V-45 Buna-N rubber (General Tire and Rubber Co, Akron, Ohio). Gen-Gard V-44 rubber was used to insulate domes and cases No. 4 and 5. Cases No. 1, 2, and 3 were not insulated.

b. Domes

Because the cylindrical section and domes for the TU-290 case were integrated in a monolithic design, the materials used in the domes were identical to those of the case: E-HTS glass for case No. 1 and S-HTS glass for cases No. 2, 3, 4, and 5.

c. Skirts

The resin system for the skirts was the same as for the cases, but E-HTS glass was used for skirts on all five cases. E-HTS glass was capable of withstanding axial loads imposed on the skirts (71, 300 lb at 792 psig).

B. TU-290 CASE NO. 1

1. Design

In the design for TU-290 case No. 1 (Figure 2), the resin content by weight in helical windings was 19.0 percent, with a density of 0.075 lb/cu in.; the resin content in the hoop windings was 17.0 percent, with a density of 0.076 lb/cu inch. The composite wall density of 0.075 lb/cu in. resulted in a strength-to-density ratio of $(1.62)(10)^6$ inches.

At the ultimate pressure of 792 psig, maximum design allowable stress, strain, and case expansion values were (for S-HTS glass):

	Stress (psi)	Strain (in./in.)	Case Expansion (in.)
Hoop glass	400,000	0.03358	---
Helical glass	360,000	0.03013	---
Composite	180,000	---	---
Dome-to-dome	---	---	3.868
Tangent-to-tangent	---	---	3.037
Radial increase	---	---	0.743

The skirts for case No. 1 were made of 80 percent helical windings and 20 percent hoop windings using E-HTS glass. This resulted in allowable strength levels of:

Compression, axial (lb)	76,800
Bending moment (in.-lb)	$(1.103)(10)^6$
Tension, axial (lb)	13,200
Shear, transverse (lb)	38,600

2. Fabrication

a. Case

The case wrapping mandrel for TU-290 case No. 1 was identical to the mandrel used for the TU-227A case. (See Volume V for a detailed description of the mandrel.) The mandrel was basically a segmented plywood structure (Figure 3) with machined plaster skin domes and a cylindrical shell. The plaster shell was coated with

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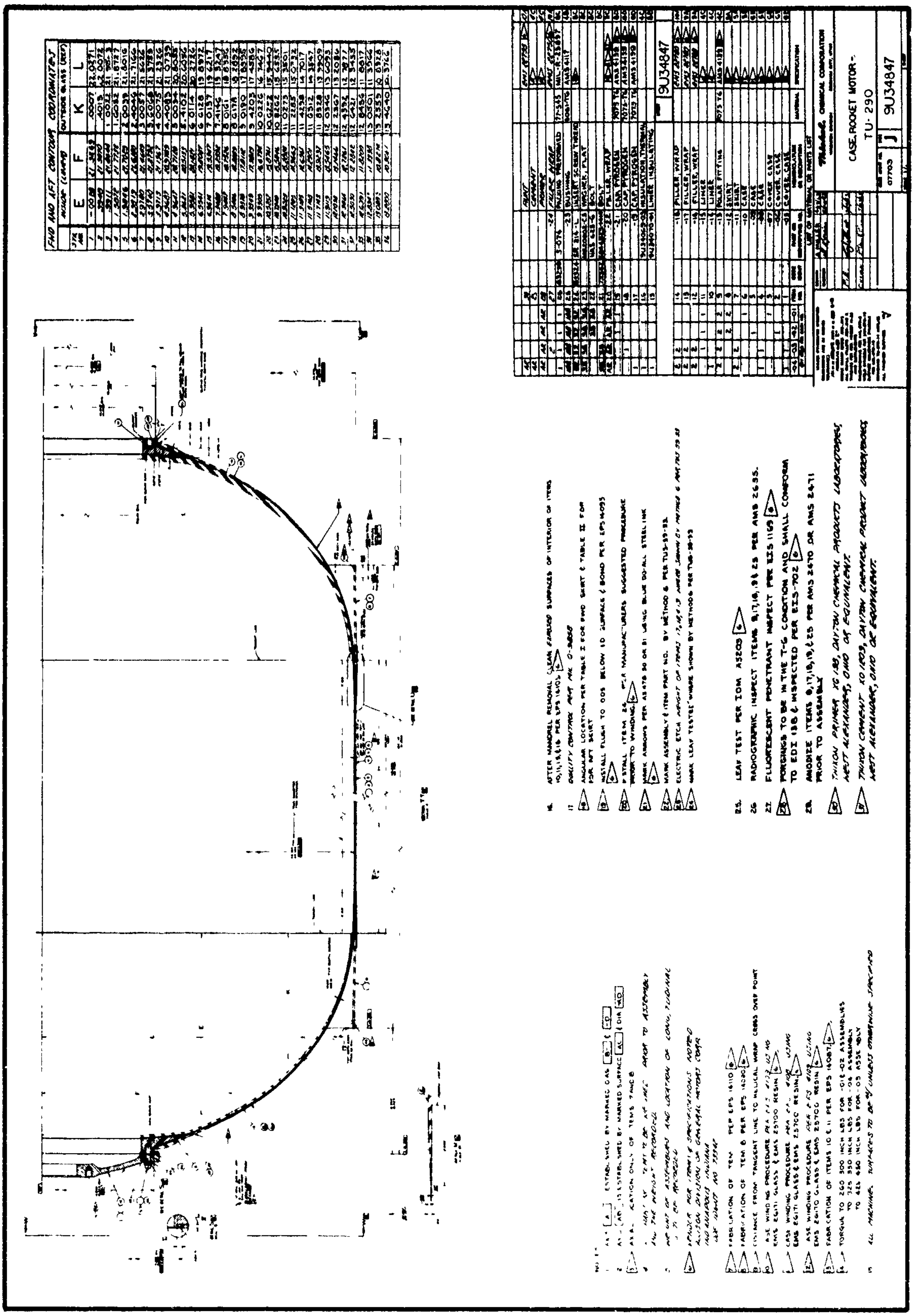


Figure 2. TU-290 Monolithic Fiberglass Plastic Case Drawing 9U34847 (Page 1 of 2)

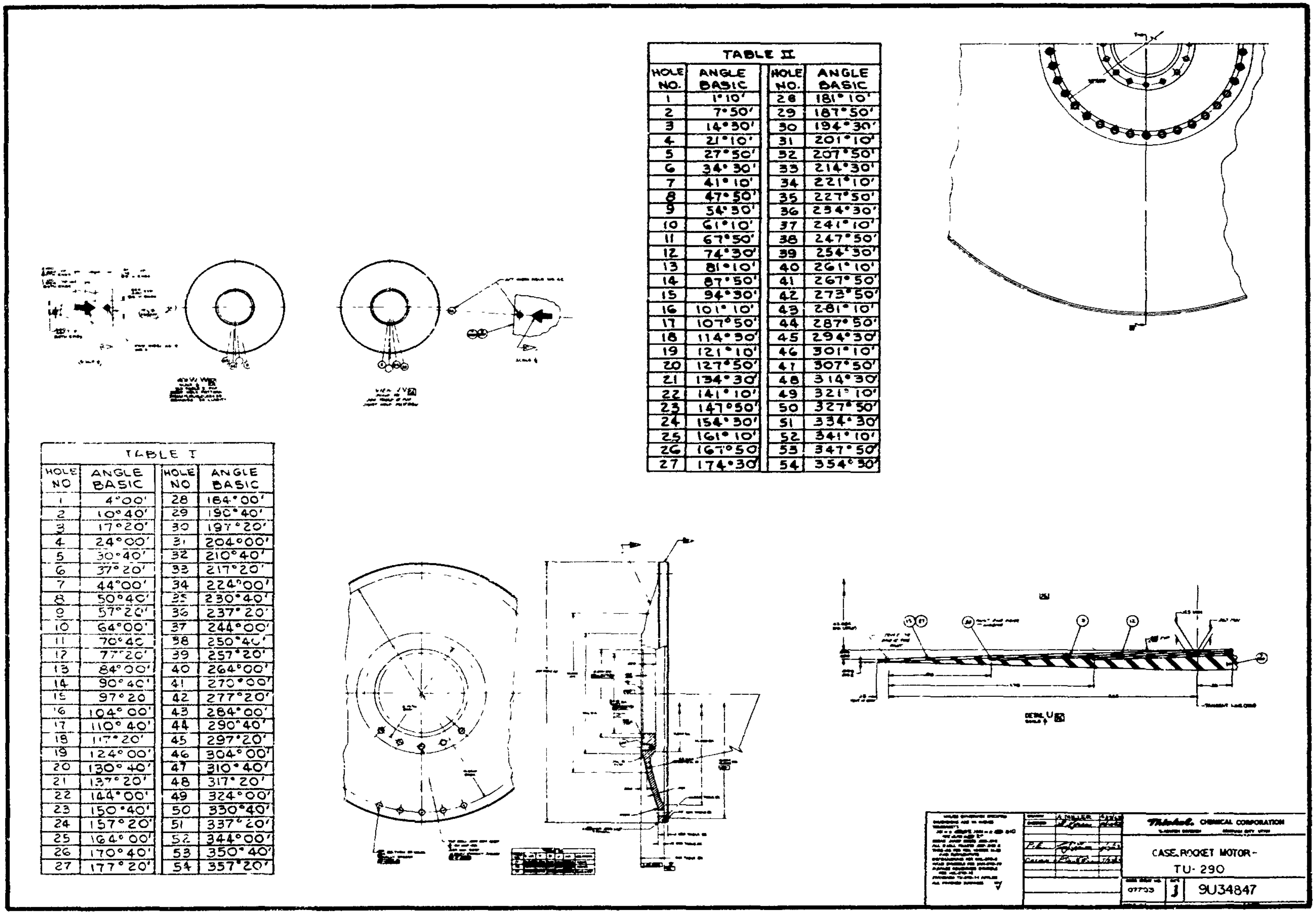


TABLE I

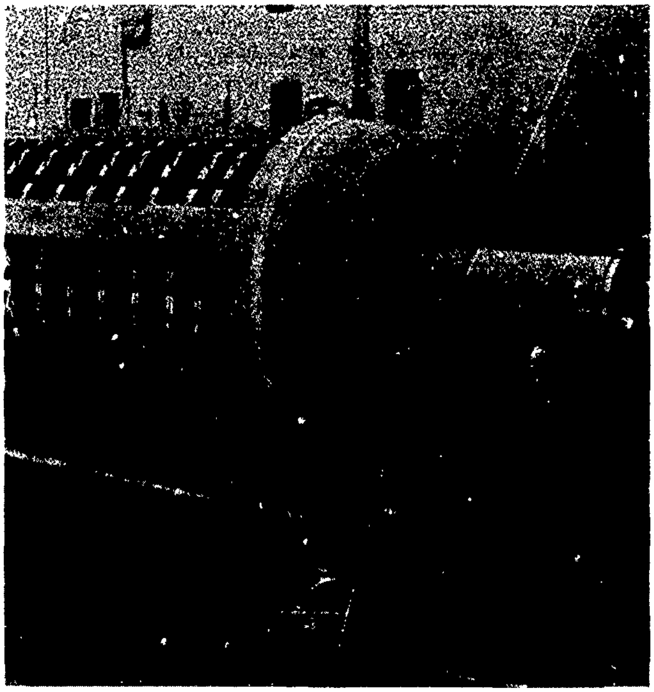
HOLE NO	ANGLE BASIC	HOLE NO	ANGLE BASIC
1	4°00'	28	184°00'
2	10°40'	29	190°40'
3	17°20'	30	197°20'
4	24°00'	31	204°00'
5	30°40'	32	210°40'
6	37°20'	33	217°20'
7	44°00'	34	224°00'
8	50°40'	35	230°40'
9	57°20'	36	237°20'
10	64°00'	37	244°00'
11	70°40'	38	250°40'
12	77°20'	39	257°20'
13	84°00'	40	264°00'
14	90°40'	41	270°00'
15	97°20	42	277°20'
16	104°00'	43	284°00'
17	110°40'	44	290°40'
18	117°20'	45	297°20'
19	124°00'	46	304°00'
20	130°40'	47	310°40'
21	137°20'	48	317°20'
22	144°00'	49	324°00'
23	150°40'	50	330°40'
24	157°20'	51	337°20'
25	164°00'	52	344°00'
26	170°40'	53	350°40'
27	177°20'	54	357°20'

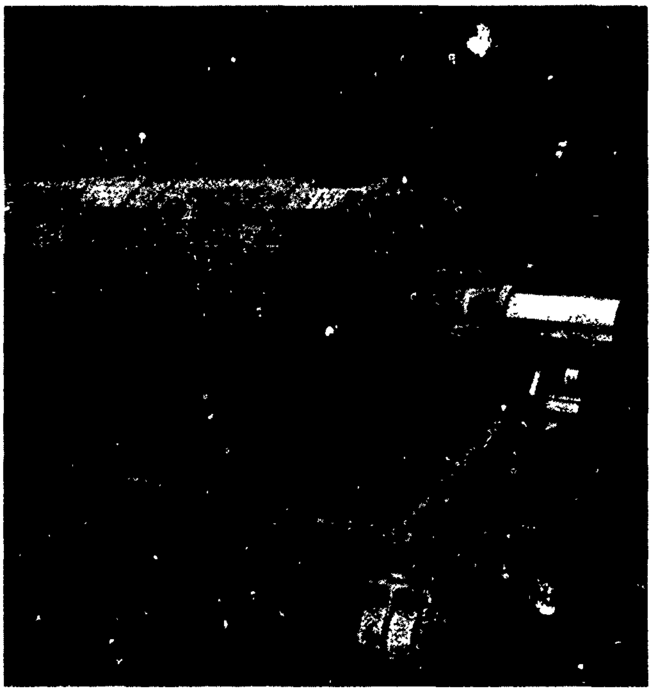
TABLE II

HOLE NO.	ANGLE BASIC	HOLE NO.	ANGLE BASIC
1	1°10'	28	181°10'
2	7°50'	29	187°50'
3	14°30'	30	194°30'
4	21°10'	31	201°10'
5	27°50'	32	207°50'
6	34°30'	33	214°30'
7	41°10'	34	221°10'
8	47°50'	35	227°50'
9	54°30'	36	234°30'
10	61°10'	37	241°10'
11	67°50'	38	247°50'
12	74°30'	39	254°30'
13	81°10'	40	261°10'
14	87°50'	41	267°50'
15	94°30'	42	273°50'
16	101°10'	43	281°10'
17	107°50'	44	287°50'
18	114°30'	45	294°30'
19	121°10'	46	301°10'
20	127°50'	47	307°50'
21	134°30'	48	314°30'
22	141°10'	49	321°10'
23	147°50'	50	327°50'
24	154°30'	51	334°30'
25	161°10'	52	341°10'
26	167°50	53	347°50'
27	174°30'	54	354°30'

Figur- 2. TU-290 Monolithic Fiberglass Plastic Case Drawing 9U34847 (Page 2 of 2)

WOOD SUBSTRUCTURE SHOWING BULKHEADS AND END DOMES





COMPLETED WOOD SUBSTRUCTURE FOR ALLISON MANDREL

Figure 3. TU-290 Case Mandrel Subsection

Gen-Gard V-57 sealant (General Tire and Rubber Co) and covered with Gen-Gard V-45 liner (Figure 4). Mandrel joints and seams were coated with six layers of Gen-Gard V-57 sealant.

The mandrel was prepared for filament winding as follows.

Five coats of a water soluble mold release agent (polyvinyl alcohol, similar to Selectron 6937, Pittsburgh Plate Glass Co, Pittsburgh, Pa.) were applied to the plaster surface. Each coat was permitted to dry 15 min before the next coat was applied, except for the fifth coat, which was permitted to dry for one hour. Two coats of Vistanex L-100 compound (Enjay Co, Inc, New York, N. Y.), a temporary, pressure-sensitive, bonding agent, were sprayed on the mandrel to provide a lightly adhesive surface for the case liner. Fifteen minutes after the first coat was applied, a second coat was sprayed on the mandrel and permitted to dry for 30 minutes.

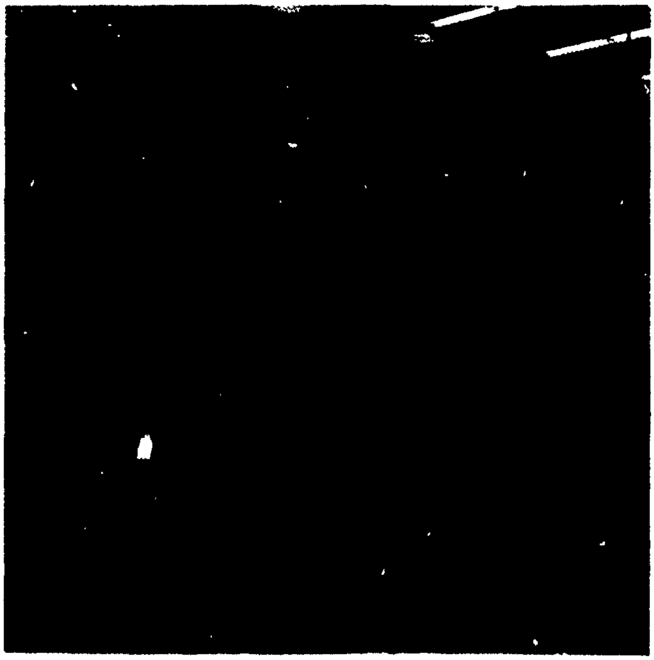
Masking, applied over pole pieces during the two preceding operations, and the pole pieces were cleaned with 1, 1, 1, trichloroethane. After 30 min of drying, the pole pieces were abraded with 120 grit emery cloth, recleaned with 1, 1, 1, trichloroethane, primed with two coats of Thixon XG-138 (Dayton Chemical Products Lab, West Alexandria, Ohio), and coated with Thixon XO-1209 cement.

The V-45 case liner was unrolled, cut to shape, and applied to the mandrel with the polyethylene protective film on the outside. After the first layer was applied, the polyethylene protective film was removed and the surface was cleaned with methyl-ethyl-ketone.

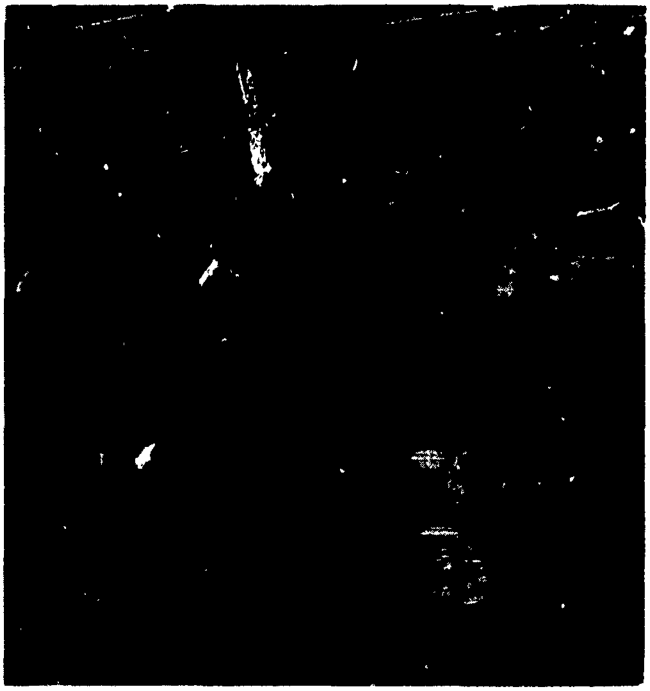
Immediately after this cleaning, the surface was scrubbed with a clean wire brush. After a 30 min drying, the second layer of V-45 liner was applied. To seal the joints in the case liner, six coats of Gen-Gard V-57 (General Tire and Rubber Co) sealant were brushed over the joints and seams. A 10 min drying time was allowed between each brushing, except the final brushing, which was allowed to dry for four hours.

While the case mandrel was being prepared, the magnesium skirt mandrel was prepared and the skirts were wound. The skirt mandrel was cleaned with methyl-ethyl-ketone, coated with carnauba wax, and buffed. Four layers of wax were applied and buffed. The skirt mandrel was then positioned in the wrapping machine (Figure 5). The winding equipment was controlled by program computer to obtain the following pattern with 12 spools of 12 end roving ribbon of E-HTS glass:

1. A single loop pattern;
2. Helical advance rate of 0.969 in.;
3. Helical wrap angle of 21.5 degrees;
4. Hoop advance rate of 0.901 in.;
5. A ribbon width of 0.950 inch.



GEN-GARD V-57 SEALANT SPRAYED ON ALLISON MANDREL



V-45 LINER APPLICATION TO MANDREL

Figure 4. TU-290 Case Mandrel

Strip heaters within the mandrel stabilized the temperature at 150° F throughout the wrapping operation. The mandrel rotation rate was set at 5 rpm. The heat helped to drain the resin from the helical hoop windings into a discontinuity area on the mandrel. Four helical layers were applied to the mandrel at 3 to 5 lb tension per spool. These helical layers were secured with one layer of hoop windings applied at 8 lb tension per spool. Twenty layers of helical and 10 layers of hoop windings were then applied to complete the skirt.

One layer of tape (Tedlar tape), which shrinks under heat, was wrapped over the windings and covered with four hoop layers of dry glass. The mandrel temperature was increased to 175°F for 5 hr without mandrel rotation for initial setting (curing) of the filaments in the resin. (The final curing of the skirts was completed during the case curing.) The strip heaters were then disconnected, the mandrel assembly cooled to room temperature, and the dry glass hoops and shrink tape removed from the mandrel. The mandrel was then placed in a lathe where the skirts were machined to design dimensions. After machining, the skirts were removed from the mandrel and stored.

Case fabrication was started immediately after the case mandrel was completed. The mandrel was positioned in the winding machine (Figure 6). The winding equipment was controlled by computer program to obtain the following pattern using 12 spools of 12 end roving ribbon of E-HTS glass:

1. Double loop pattern;
2. Helical (wrap) angle of 21.5 deg;
3. Wrapping advance rate of 0.963 in.;
4. Ribbon width of 0.925 in. to 0.975 in.;
5. Forward and aft crossover-to-tangent line distance of 7.25 in.;
6. End opening enlargement rate of 0.2 percent.

Eight layers of helical windings were applied to the case mandrel. The skirts were then removed from storage, cleaned with methyl-ethyl-ketone positioned on the mandrel and secured by hoop windings. Eleven layers of hoop windings were applied between the two tangent points on the case.

Before the case was placed in the curing oven, the resin was partially cured to set the filaments in place by positioning heat lamps around the case (175°F) for four hours. The heat lamps were then disconnected, and the case was cooled to room temperature. All surface temperatures were determined with an optical pyrometer.

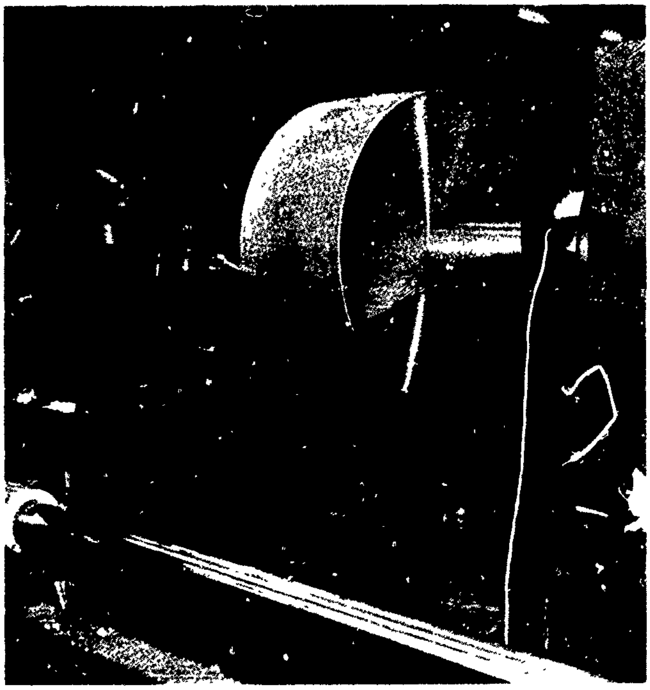


Figure 5. TU-290 Case Skirt Fabrication

After the resin had set, the case on the mandrel was removed from the winding machine and placed in the curing oven. Curing was accomplished by rotating the case at 1 to 2 rpm while the temperature was varied according to the following sequence.

1. Four hours at 200°F to 225°F.
2. Four hours at 250°F to 275°F.
3. Four hours at 300°F to 325°F.
4. Eight hours at 325°F to 350°F.

After the case was cured for 8 hr at 325°F to 350°F, the oven was turned off and oven intake and exhaust ports were opened to lower the internal case temperature to 200°F. The oven doors were opened partially to control the rate of cooling at 25°F per hour. When the case temperature dropped to 100°F, the oven doors were opened completely and the case was removed from the oven.

The mandrel was removed from the case through the forward and aft ports and the case was placed on a dolly (Figure 7). Design and actual weights of the case are compared in Table II.

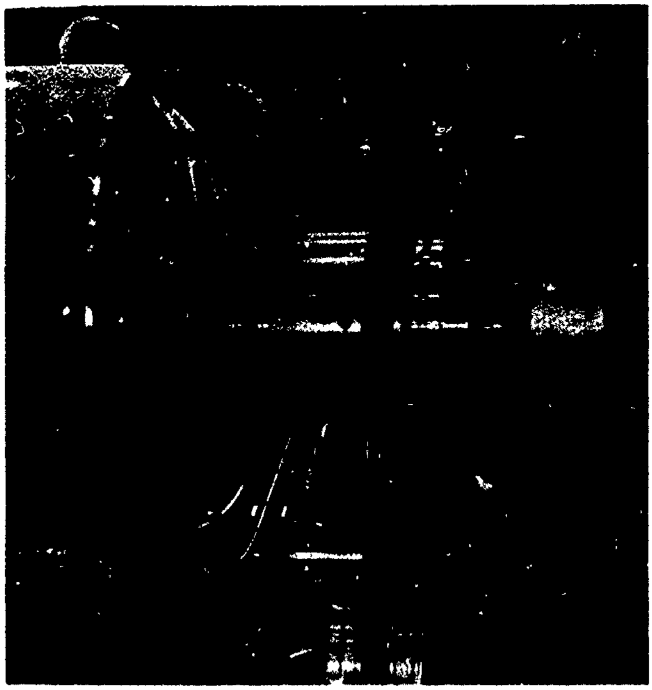
To remove the residual plaster, mold release, pressure sensitive adhesion system, and to uncover the V-45 liner, 5 gal. of hexane was placed inside the case, and the case was rotated at 4 rpm. Once the materials were loosened from the case interior, they were removed through the case ports. The release agent did not release all of the plaster as intended, and some difficulty was experienced in removing the plaster from the liner. Approximately 2 to 6 lb of plaster remained in the case.

3. Test

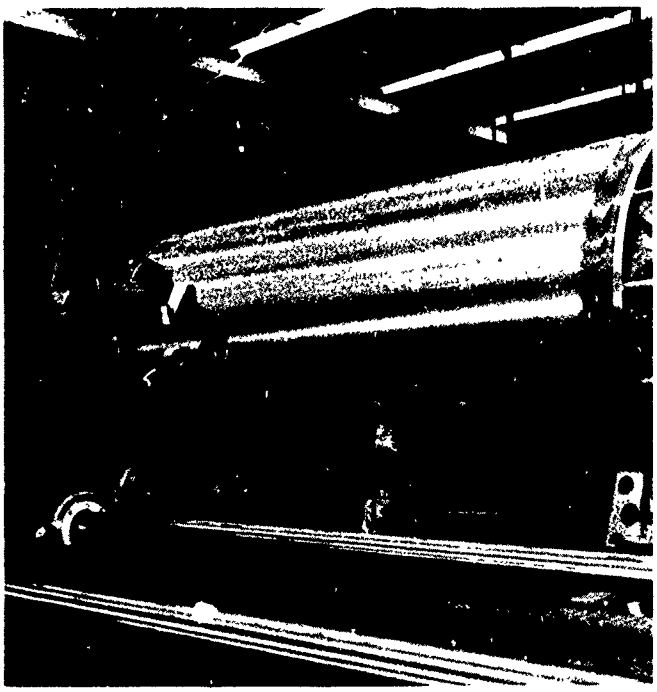
The instrumentation and hydrostatic testing to destruction of TU-290 case No. 1 was conducted at Allison and is described below.

a. Test Preparation

Baldwin PA-3 strain gages (Baldwin-Lima-Hamilton, Waltham, Mass.) were used to measure case growth. The gages were attached to the case with a cement which maintained a bond until the fiberglass was stressed beyond its yield strength. Baldwin AF-7 gages, similarly cemented, were used to measure strain in the PYROGEN igniter cover. Longitudinal and radial case deflections were measured by linear potentiometer indicators (connected to 20 gage piano wire encased in Teflon tubing wrapped around and fixed to the case). Forward dome deflections were measured relative to the forward skirt, and aft dome deflections were measured relative to the aft skirt. The locations of these measurement devices are shown in Figures 8 thru 10.



Skirt positioning



Hoop winding

Figure 6. TU-290 Case Fabrication

TABLE II

TU-290 CASE NO. 1 WEIGHT SUMMARY

Item	Design Weight (lb)		Actual Weight (lb)	
Fiberglass	128.5		139.0	
Skirts	20.0		22.2	
Case liner	50.0		55.6	
Polar fittings	19.2		17.2	
Threaded inserts	0.3		--	
Subtotal, case assembly		218.0		234.0
O-ring seal	0.1		0.1	
PYROGEN cap	8.8		8.7	
Flat washers	0.1		0.2	
Bolts	1.9		1.2	
Threaded inserts	0.1		--	
Total, case assembly		229.0		244.2

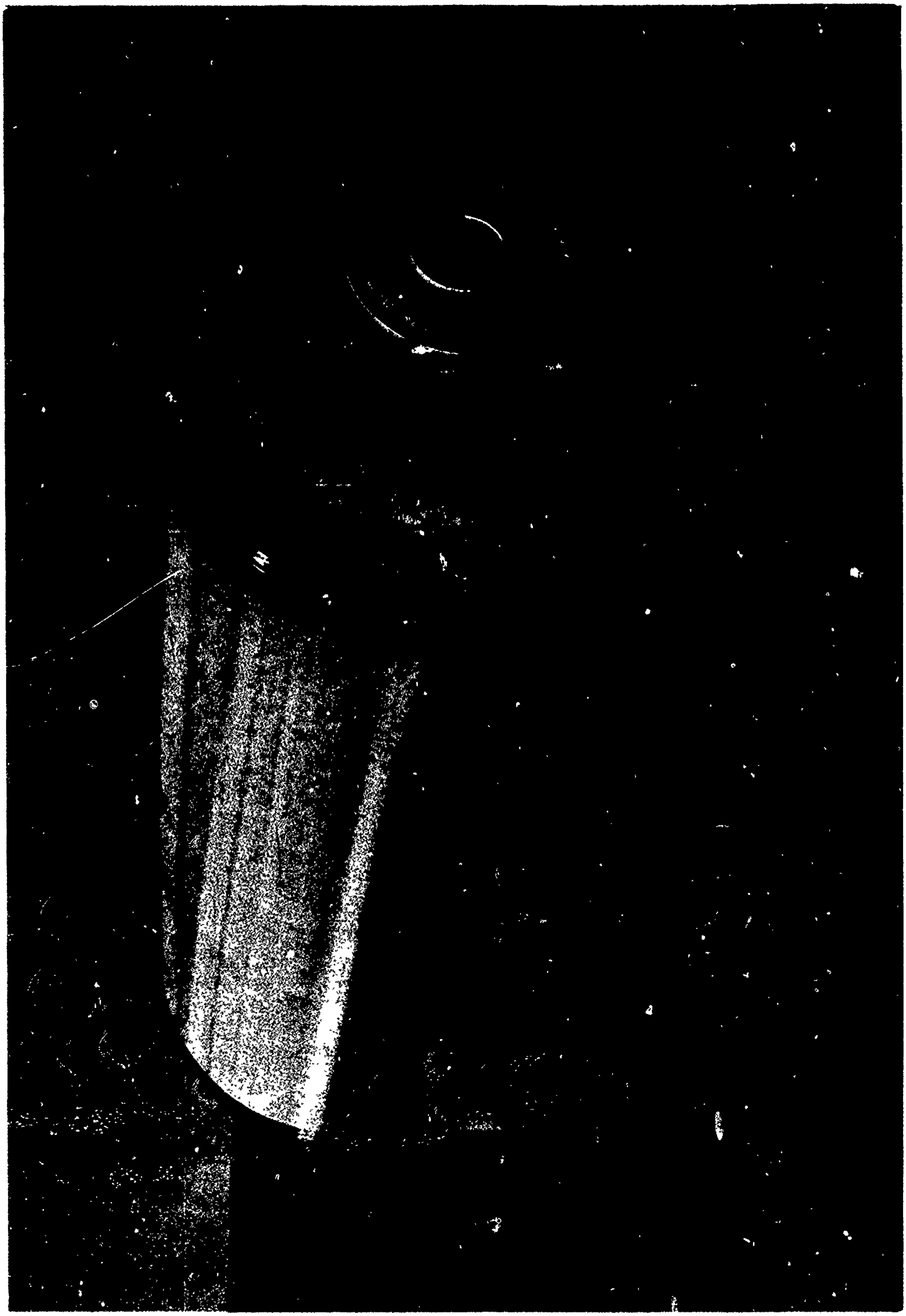
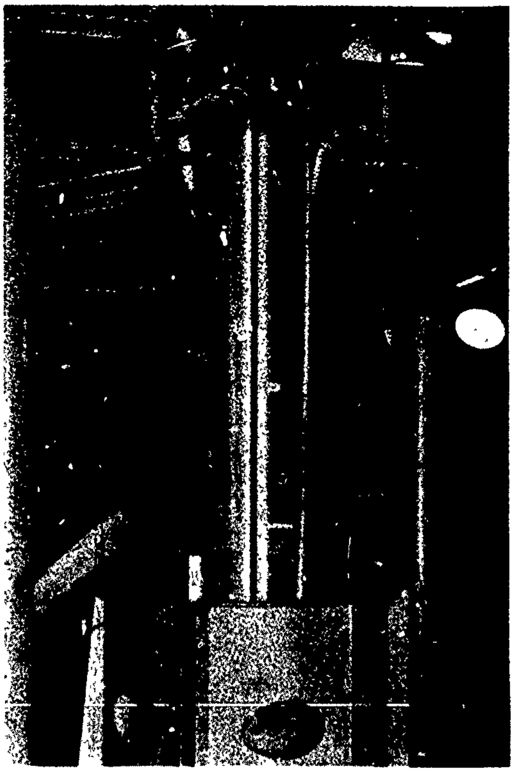
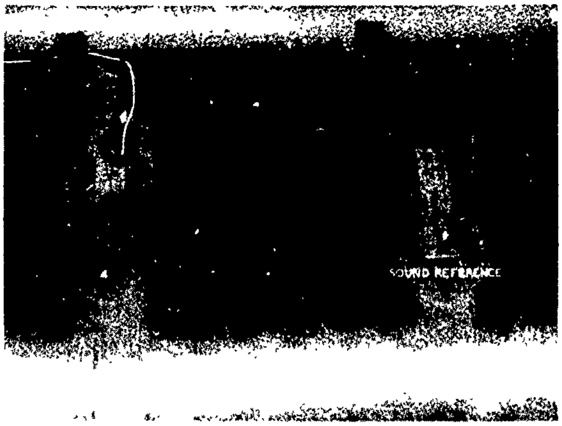


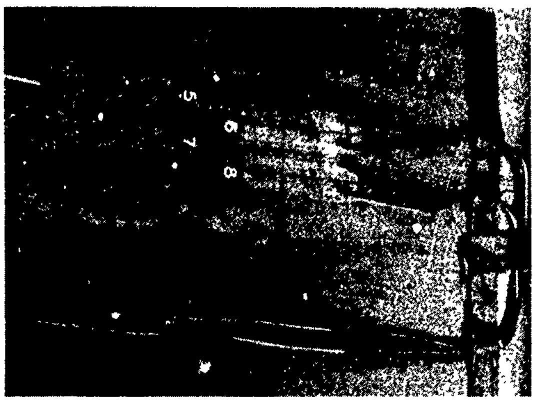
Figure 7. Completed TU-290 Case No. 1



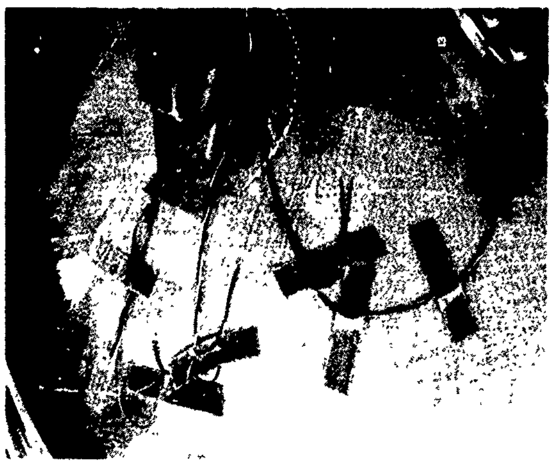
TU–290 Case No. 1
in Test Facility



Sound Reference and Strain
Indicator 4 (Top of Case)

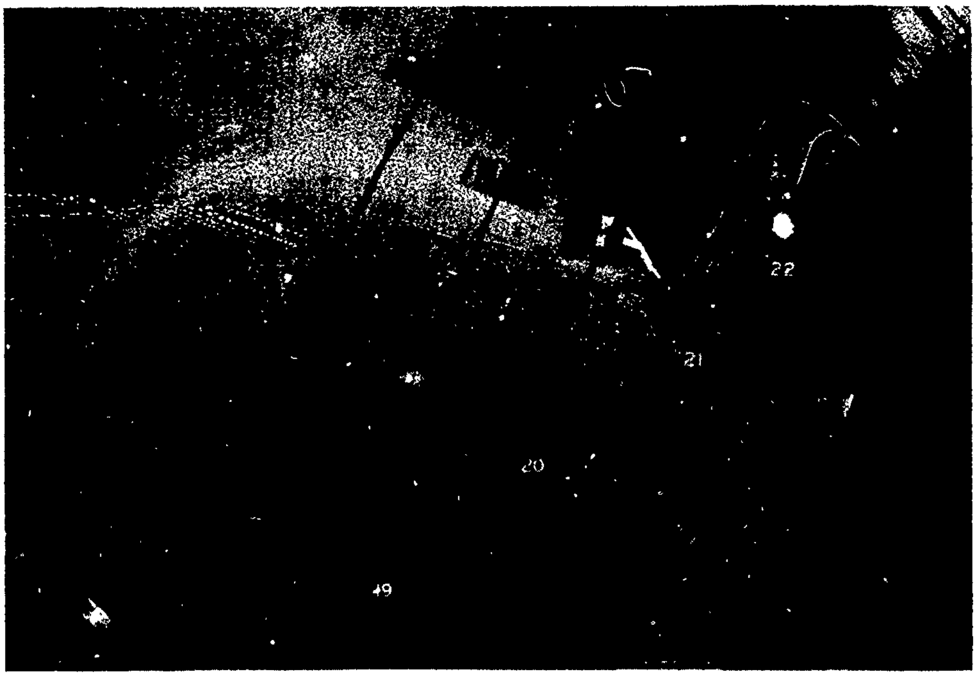


Strain Indicators 5 Thru 8
(Top of Case)



Indicators 13 Thru 17
(Top of Case)

Figure 8. TU-290 Case No. 1 Aft Dome Instrumentation



Indicators 18 thru 22

Indicators 23 and 24

Figure 9. TU-290 Case No. 1 Forward Dome Instrumentation

Deflections were recorded continuously as a function of time on strip chart and oscillograph recorders. Case noises (caused by resin cracking) were monitored through three contact microphones.

The case was mounted in the test stand in a vertical position and supported on the forward skirt. A sleeve and piston were mounted in the nozzle port to transmit pressure from within the case to the forward skirt through the test stand frame. The piston was designed to transmit a load of 71,300 lb at 792 psig. Force against the piston acted against the forward skirt, after being transmitted through the frame of the stand. Water was pumped into the case through a port in the forward dome. The desired water pressure was obtained by successively using additional pumps to increase flow, while maintaining pressure, as the case expanded.

d. Test Program

The hydroburst test of TU-290 case No. 1 was conducted to demonstrate the structural integrity of the case, verify designs and fabrication techniques, and obtain stress and strain data to evaluate the potential strength of S-HTS glass for cases No. 2, 3, 4, and 5. A burst pressure of 700 psig and hoop fiber stress of 350,000 psi were predicted for the case.

The test program (Figure 11) specified (1) an internal pressure check at 50 psig for 300 sec to condition the instrumentation and establish case integrity, (2) a linear pressure increase to 660 psig in 30 sec to test the case for growth and expansion, and (3) a sustained internal pressure of 660 psig for 60 sec to test the case at proof strength. The pressure medium for the test was water.

c. Case Testing

Cracking noises were heard immediately when the case internal pressure was raised to 50 psig. The intensity of the cracking noises increased to approximately 40 db above the pump sounds, then ceased while the pressure was held steady at 50 psig. Individual cracking noises were neard during the pressure check at 50 psig, as indicated by the dotted lines in Figure 12. Intense cracking began with the application of additional pressure; the noise level increased to a peak at approximately 30 percent of burst strain pressure, then began to decrease. At approximately 50 percent of burst strain pressure, only occasional minor cracking noises were heard. Since all microphones picked up approximately the same sounds, microphone location was not considered critical.

The case failed at 575 psig while the internal case pressure was being increased toward the proof pressure level of 660 psig. At the time of failure, the pressure buildup was 53 sec behind the programed pressure buildup (Figure 11). The failure originated in the hoop fibers of the cylindrical section 47 in. aft of the forward skirt (Figure 13). All strain data appeared to be valid. Premature failure of several gages resulted from severe circumferential resin cracking in the hoop windings on the cylinder.

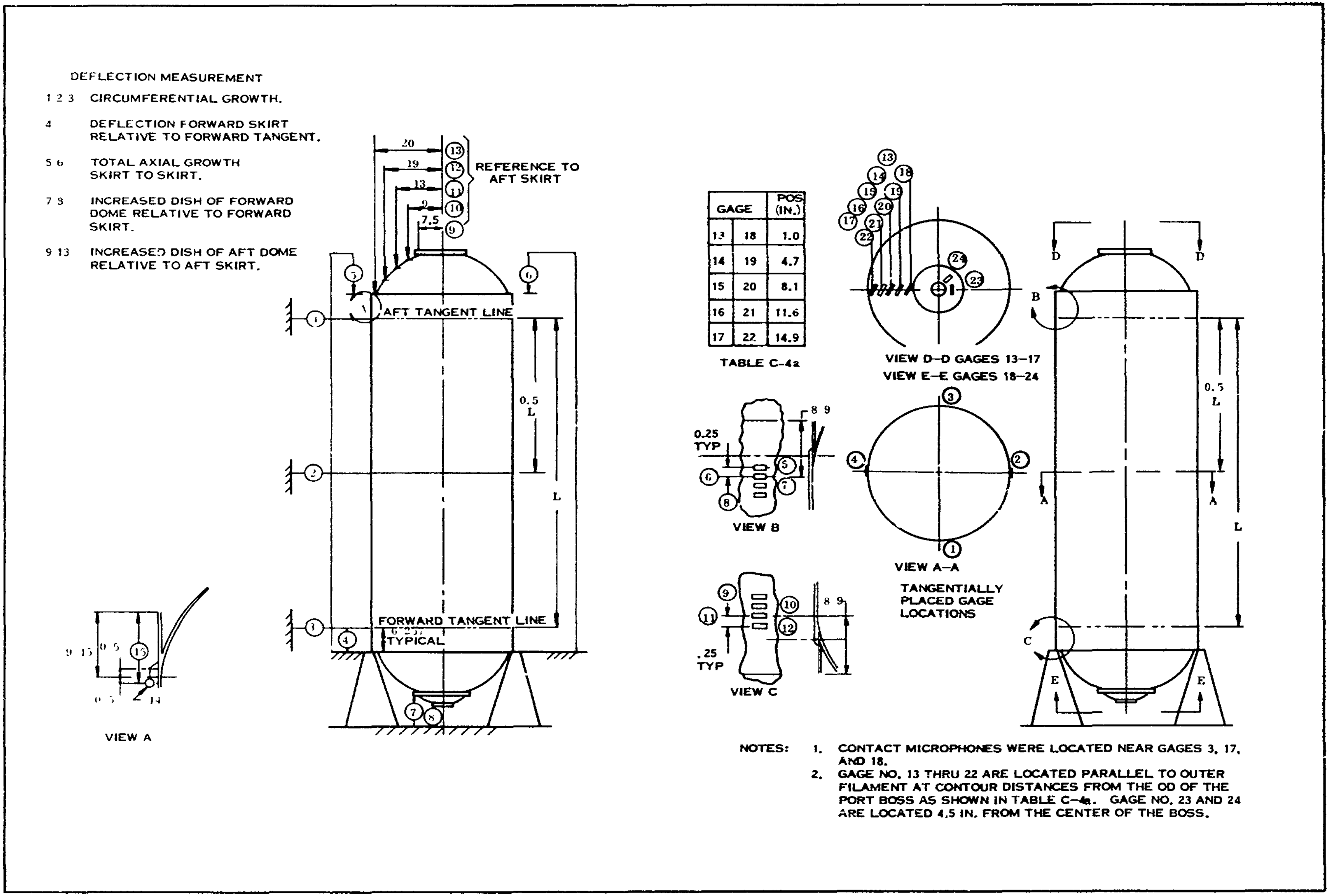


Figure 10. TU-290 Case No. 1 Hydroburst Test Instrumentation Arrangement

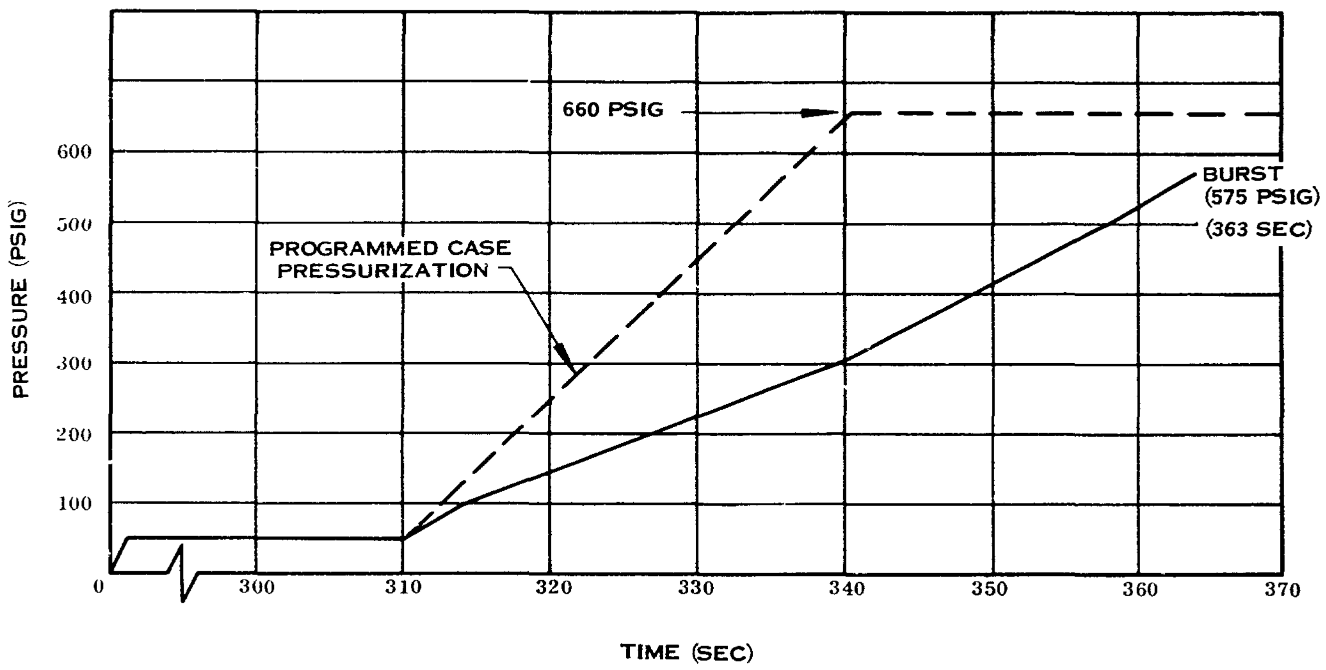


Figure 11. TU-290 Case No. 1 Hydroburst Test Pressure Record

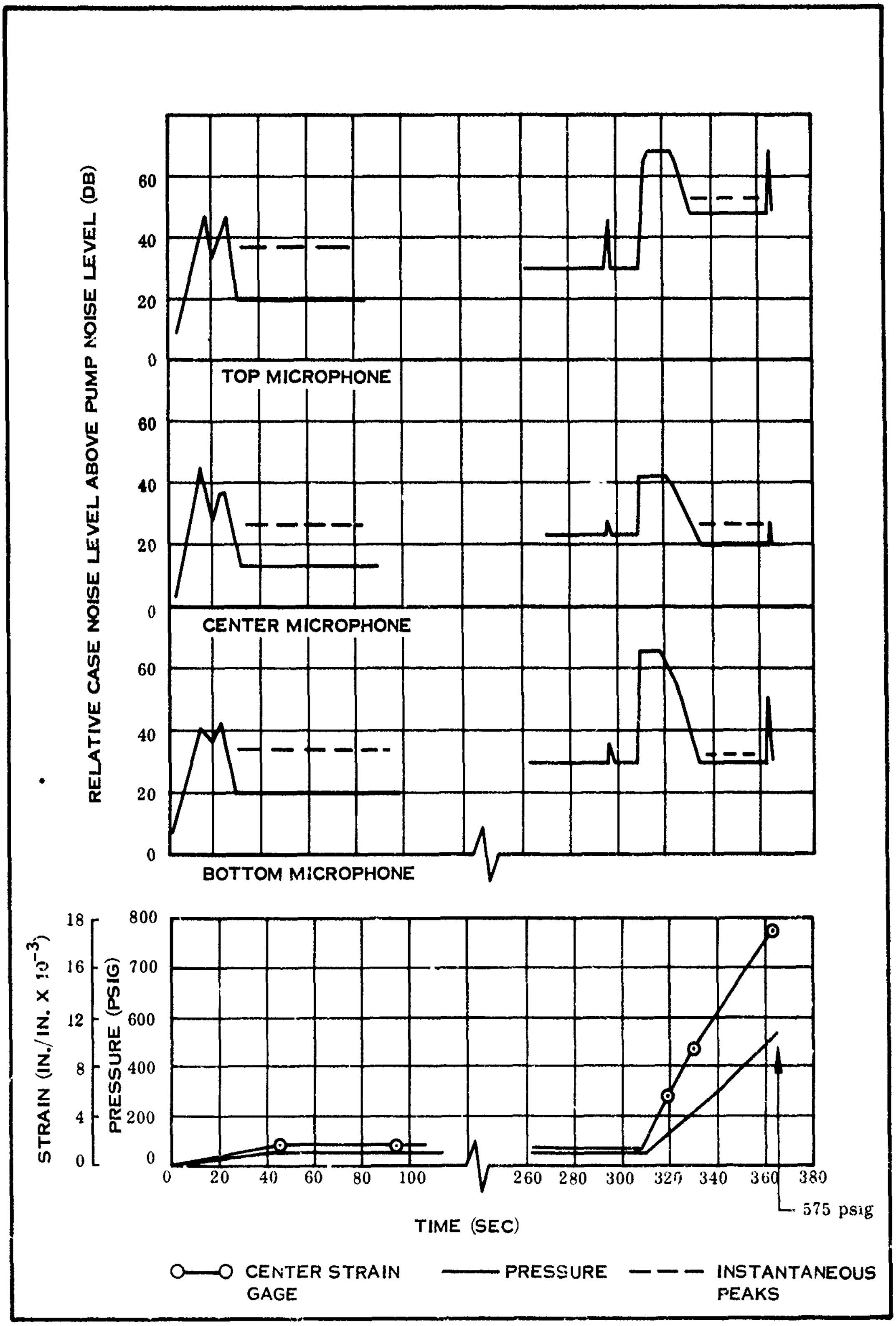


Figure 12. TU-290 Case No. 1 Hydroburst Test Noise Record

Because deformation in the forward dome was greater than had been expected, the range of the potentiometers was exceeded. The behavior of potentiometers No. 9 and 11 was erratic (Figure 14). All potentiometers on the aft dome failed at 500 psig. As nearly as can be determined, all instrumentation was working properly (Figure 15).

The pertinent test data for the first TU-290 case are summarized below.

Burst pressure (psig)	575
Design wall thickness (in.)	0.098
Actual wall thickness (in.)	0.105
Ultimate strength (PR/t; psi)	121,000
Maximum hoop fiber stress (psi)	290,000

Maximum hoop fiber stress, σ_{hoop}, was determined as follows:

$$\sigma_{hoop} = \frac{(D)(P)(S_c)(2 - \tan 2\alpha)}{(4)(a_e)(e_c)(N_c)}$$

Where:

D = Case diameter (in.)

P = Case pressure (psig)

S_c = Spacing of circumferential windings (in.)

α = Helix angle

a_e = Area of end (204 filaments per end; sq in.)

e_c = Number of ends

N_c = Number of layers

4. Evaluation and Analysis

The premature case failure at 575 psig was attributed to the 53 sec lag of pressure application in the case (relative to programed pressure application). The failure to apply pressure at the programed rate permitted glass fibers to abrade adjacent fibers during case expansion, and the abrasions reduced the strength of the E-HTS glass. The manner of adding pumps to sustain water pressure and volume during case expansion was imperfect, which limited the water volume output of pumps during the hydroburst test.

Although the burst pressure and hoop fiber stress test objectives (700 psig and 350,000 psi, respectively) for the first case were not fully met, the test results indicated that S-HTS glass used with the basic designs and fabrication techniques would be satisfactory for the remaining four TU-290 cases.

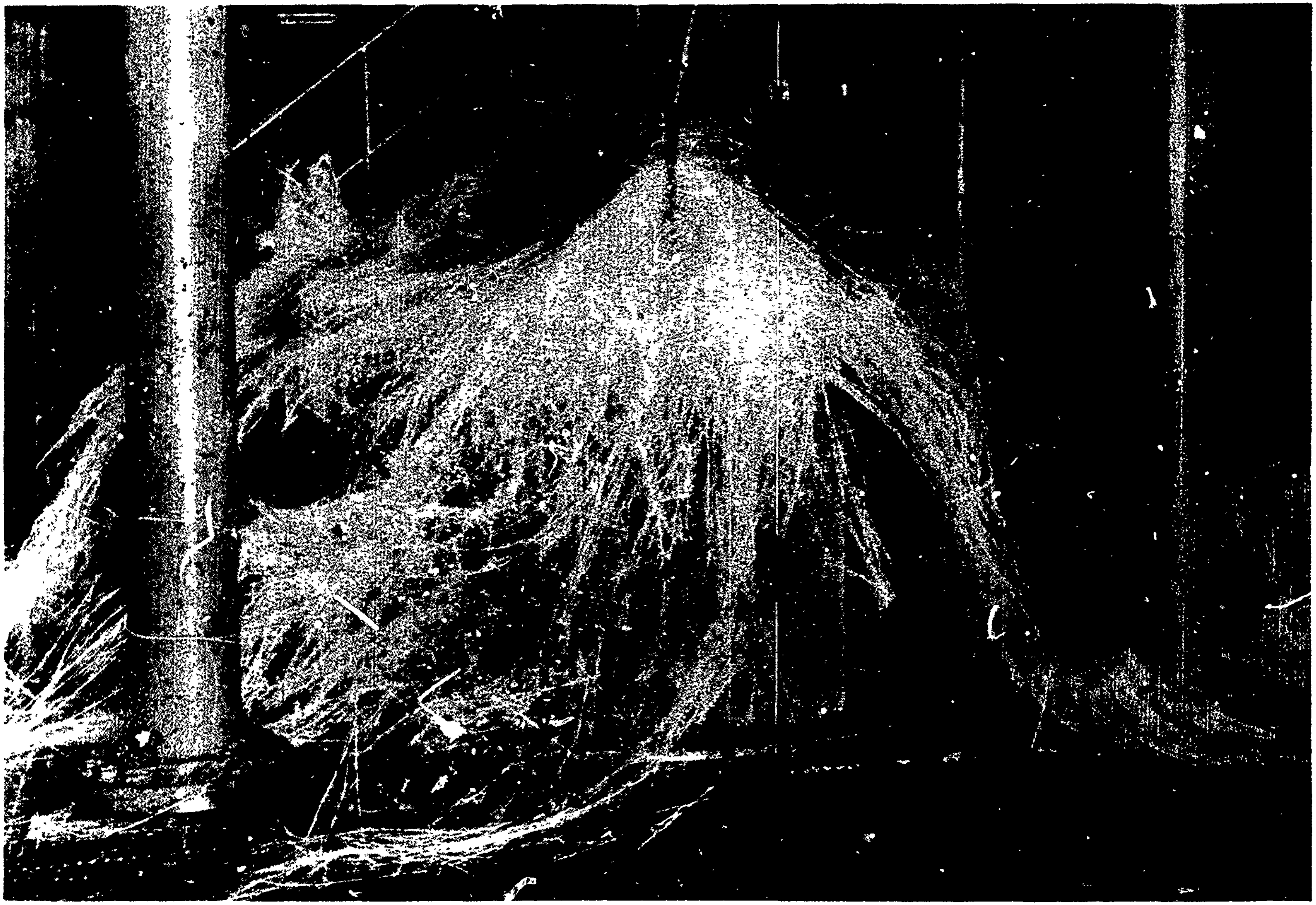


Figure 13. TU-290 Case No. 1 After Hydroburst Testing

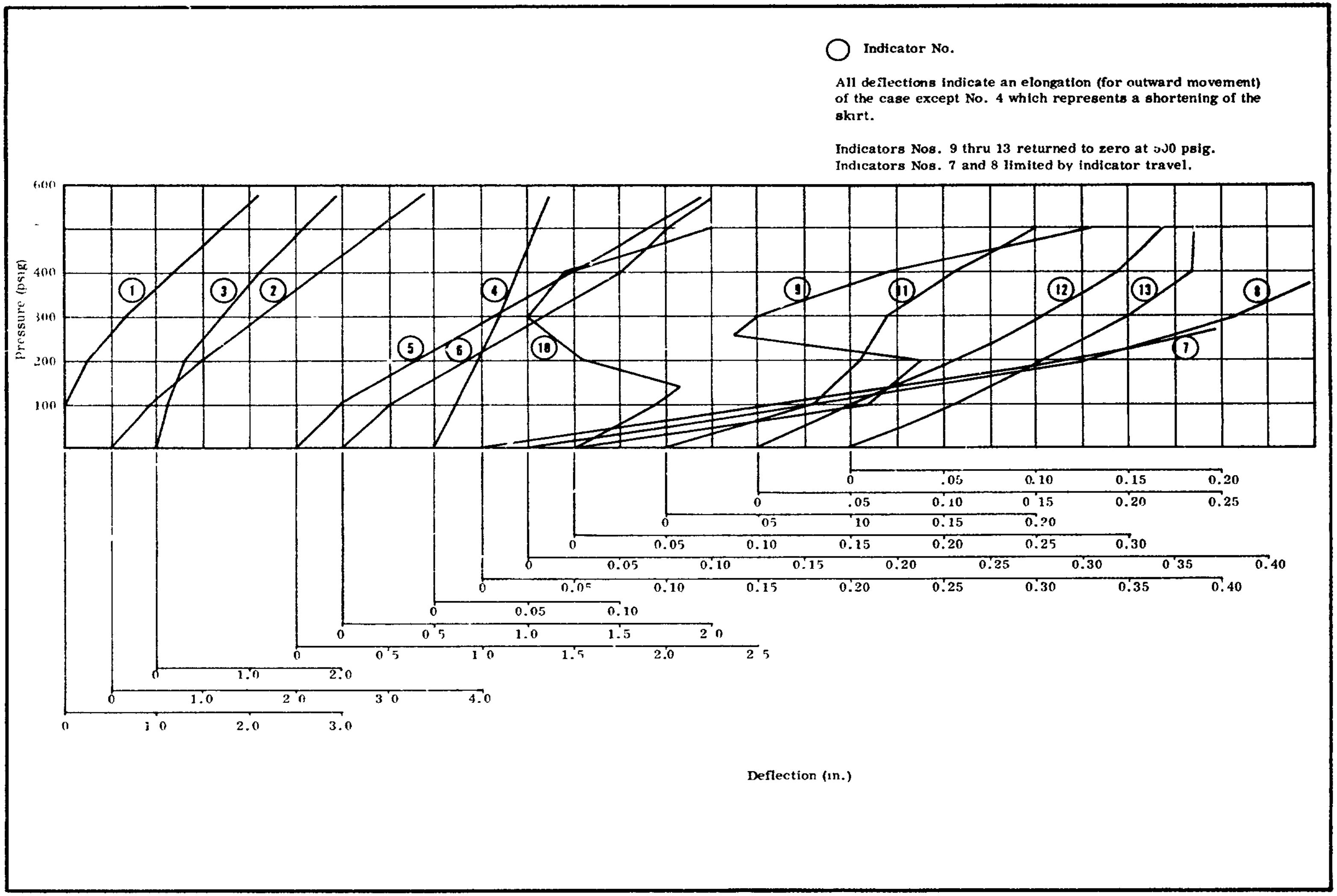


Figure 14. TU-290 Case No. 1 Hydroburst Test Deflection Indications

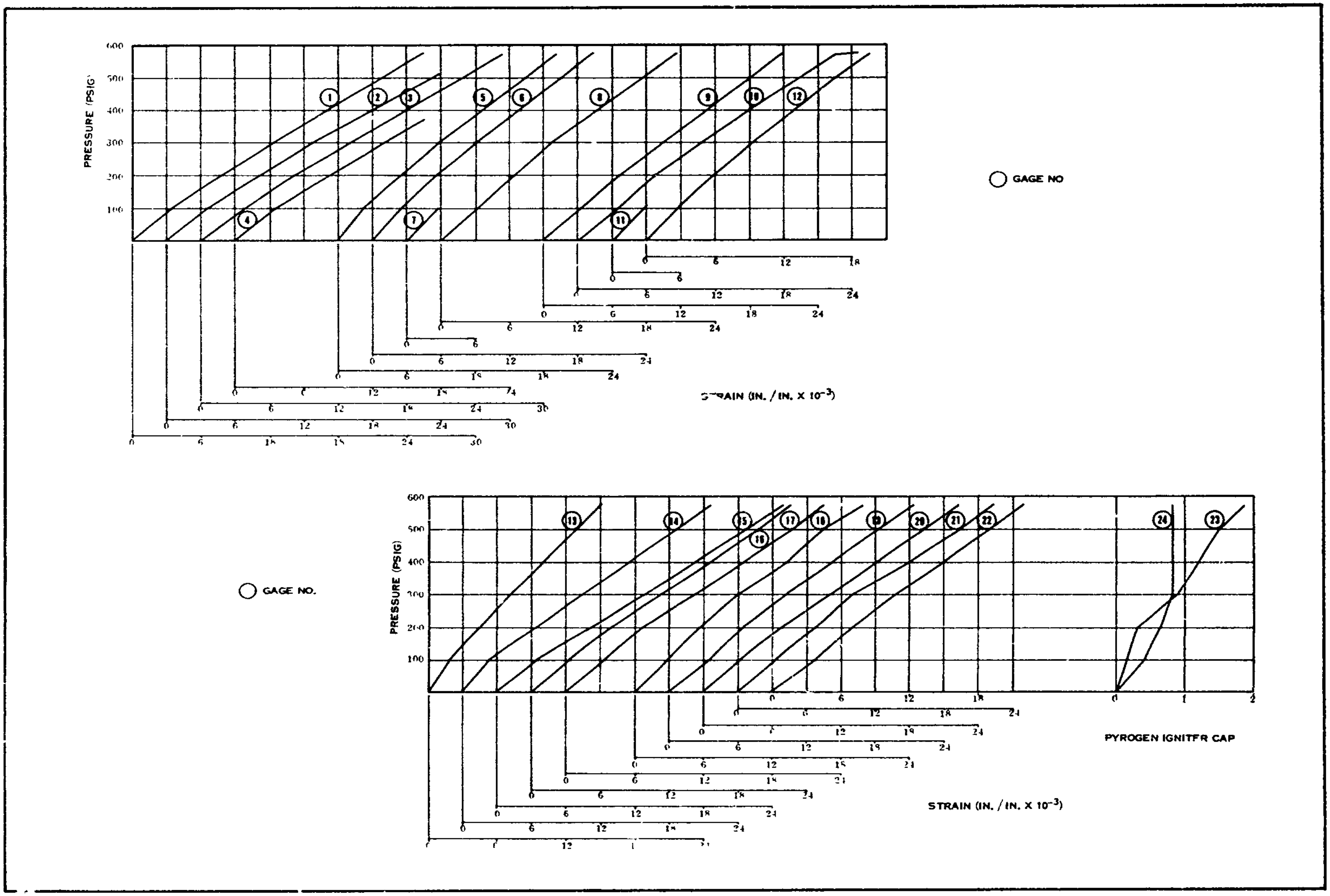


Figure 15. TU-290 Case No. 1 Hydroburst Test Strain Indications

C. TU-290 CASE NO. 2

1. Design

The main objectives for the fabrication and test of case No. 1 were to establish the basic design of the TU-290 case and evaluate E-HTS glass. For case No. 2, the objective was to evaluate the case design using S-HTS glass. The design, wrapping pattern, hardware attachments, and winding equipment remained the same.

2. Fabrication

a. Skirts

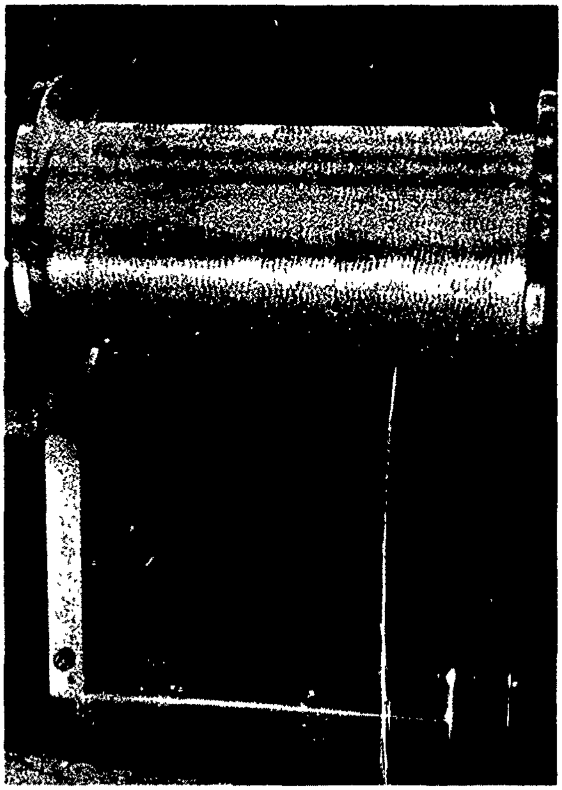
The fiberglass skirts for case No. 2 were wrapped with E-HTS glass without difficulty. While the skirts were being machined with a single point tool, however, the fiberglass layers separated. New skirts, on which finished surfaces were ground (rather than machined), were prepared. Grinding, rather than machining with a single point tool, was used for all subsequent skirt operations to prevent fiberglass layer separations.

b. Case

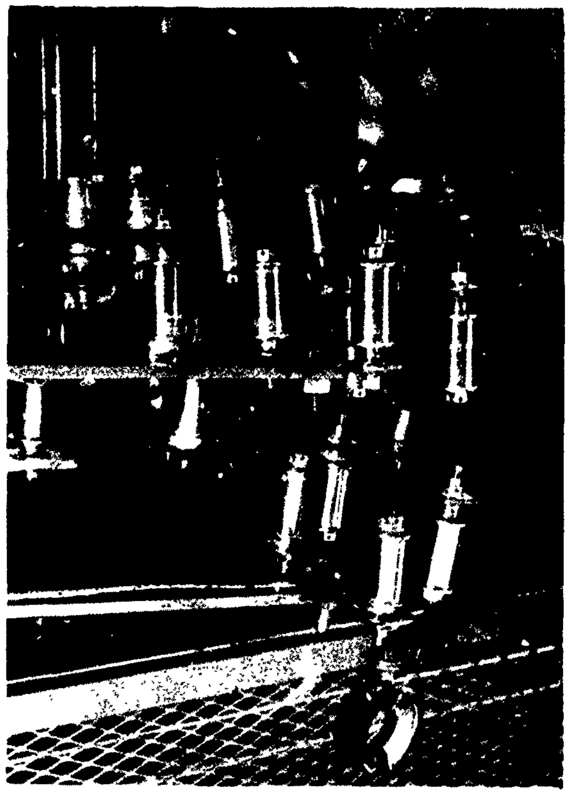
Computation of the design strength of case No. 2 was based on the use of S-HTS glass with a filament diameter of 0.00037 inch. The 0.00037 in. dimension was quoted by the fiberglass supplier, Owens-Corning. During quality control acceptance testing of materials for case No. 2, however, Allison calculated the filament diameter of the S-HTS glass (based upon the yield from the glass spools) to be 0.00036 inch. This observation was documented for consideration and analysis after case No. 2 was hydroburst tested.

While case No. 2 was being wrapped, considerable fraying and breaking of S-HTS glass fibers was observed as glass was fed onto the case mandrel. Figure 16 shows broken strands of fiberglass on the glass transfer machine and glass fraying on a spool of glass. The exact details of the fraying and breaking were noted and wrapping of the case was completed without additional problems.

While the mandrel segments were being removed from the case, difficulty was again encountered in removing the plaster from the case liner. Because similar difficulty was experienced in removing the plaster from case No. 1, a new release agent was selected for cases No. 3, 4, and 5. After the mandrel was removed, the case was placed on a dolly. The design weight and actual weight of the case are compared in Table III.



Broken Filaments, Scuffed Fibers on Spool of S-HTS Fiberglass



Broken S-HTS Fiberglass Fibers on Glass Transfer System

Figure 16. TU-290 Case No. 2 Fabrication - Glass Scuffing

TABLE III

TU-290 CASE NO. 2 WEIGHT SUMMARY

Item	Design Weight (lb)		Actual Weight (lb)	
Polar fittings	19.2		17.0	
Case liner	50.0		48.8	
Fiberglass	128.5		125.6	
Skirts	20.0		23.1	
Threaded inserts	0.3		--	
Subtotal, case assembly		218.0		214.5
O-ring seal	0.1		0.1	
PYROGEN cap	8.8		8.7	
Flat washers	0.1		0.2	
Bolts	1.9		1.2	
Threaded inserts	0.1		--	
Total, case assembly		229.0		224.7

While case No. 2 was being fabricated, Thiokol and Allison conducted investigations to determine causes for the fraying and breaking of S-HTS fiberglass. Thiokol, contacting other companies in the industry which used S-HTS glass, learned of similar problems with fiberglass wrapping operations. Owens-Corning was informed of Allison's wrapping problem. Owens-Corning could not explain reasons for the glass damage, and could not suggest immediate solutions to the problem. However, a representative was sent to Allison to study the problem.

Allison discovered that the direction of winding on the spools of glass (the direction in which glass strands are wound onto, or unwound from, the spool, known as "waywind," or as "lead" or "lag" in the winding pattern of the spools) differed from that of E-HTS glass. E-HTS glass had a lead waywind, but the S-HTS glass used in case No. 2 had a lag waywind. The difference was not noticeable unless the spools were observed closely while they were unwinding. The difference in waywind caused the unwinding S-HTS glass strands to scuff across adjacent strands (Figure 17) and damage the glass. The scuffing and fraying was particularly noticeable at the ends of the spools. Allison showed that, with a lead direction of waywind, the strand being unwound left the spool without damaging the adjacent strands.

While Owens-Corning did not feel that the direction of waywind contributed to the frayed and broken strands of S-HTS glass, a spool of S-HTS glass with a lead waywind was forwarded to Allison for additional tests. Transfer characteristics of spools of S-HTS glass with lead waywind and lag waywind, and a spool of E-HTS glass with a lead waywind were compared (Figure 18). The spool of S-HTS glass with lag waywind (center spool: Figure 18) showed the greatest damage to the glass. Glass was frayed at the ends and fibers were found on the roller below the spool. A demonstration was presented to Owens-Corning personnel to show them how the waywind direction affected the strength of the glass.

Because the strands of glass used to wrap case No. 2 were frayed and broken, predicted strength data for the case were invalid. To determine whether the case was strong enough to yield significant data during hydroburst testing, Allison conducted a tensile strength test on the frayed S-HTS glass.

Lengths of roving from the spool of S-HTS glass (each 36 in. long) were impregnated with a resin system (Union Carbide ERLA 2260 epoxy resin and ZZL-0820 hardener, cured for 60 min at 250°F and 60 min at 350°F). Specimens cut 18 in. long were installed in a tensile tester, and loaded to failure at a crosshead speed of 0.5 in. per minute. The average tensile strength of the test specimens was 581,000 psi. While the strength of case No. 2 was below the minimum specification value set by Allison (600,000 psi for S-HTS glass), the case was accepted for hydroburst testing because the test showed that damaged S-HTS glass was still stronger than E-HTS glass used in case No. 1.

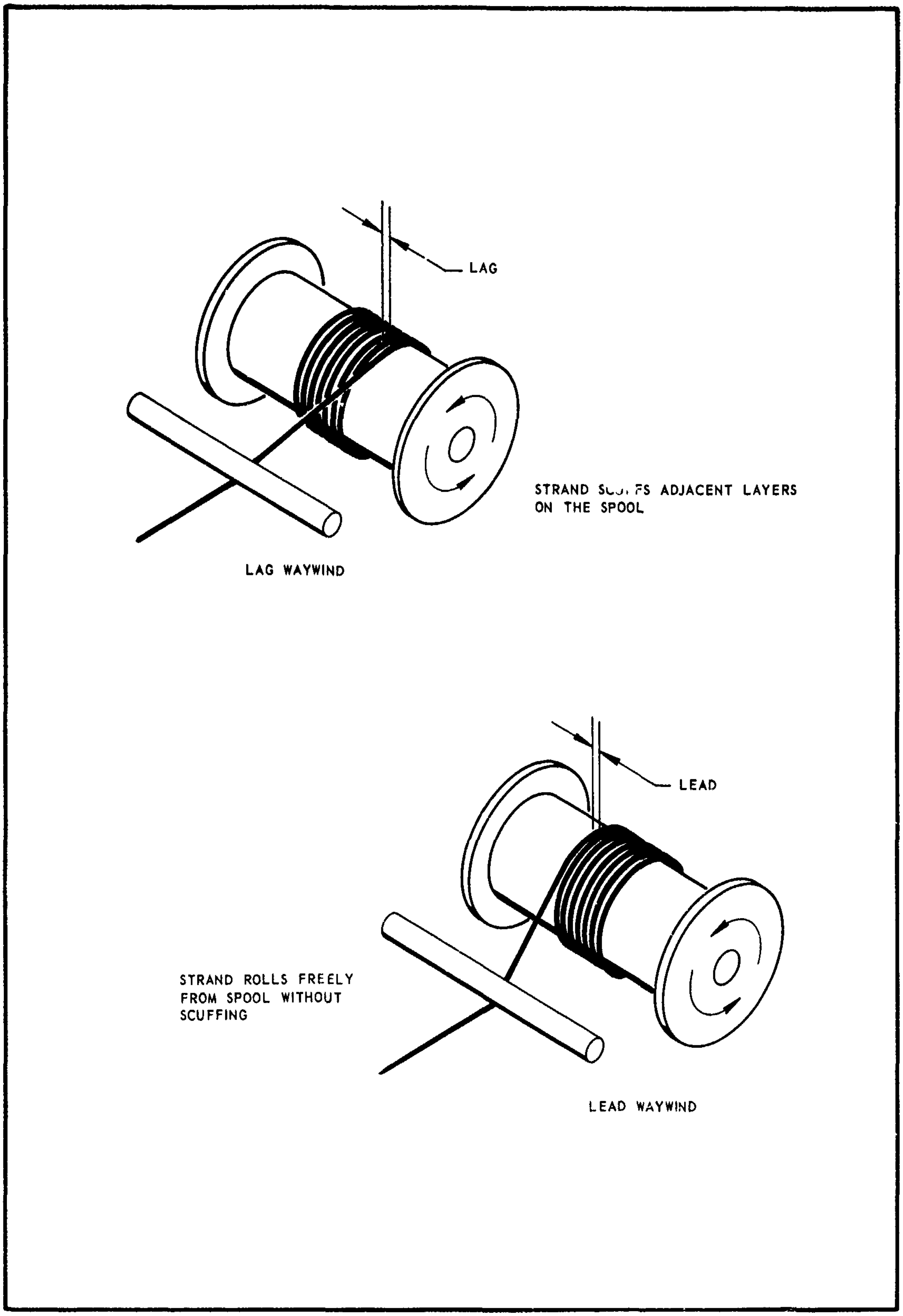


Figure 17. Spool Winding Methods for S-HTS Glass

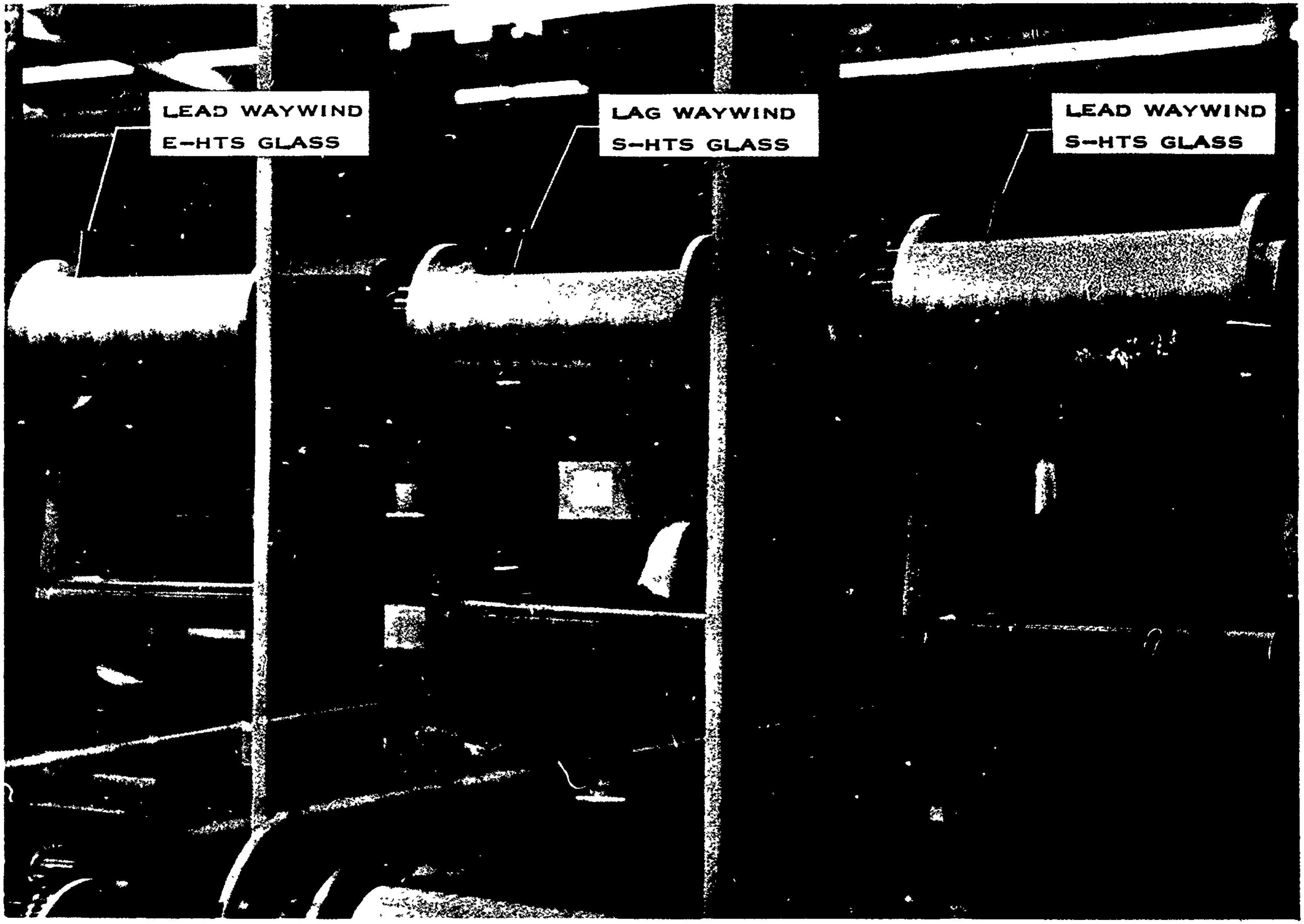


Figure 18. Fiber Damage Due to Lag Direction of Waywind

As a result of the fraying problem, the Allison material acceptance specification for S-HTS glass to be used on cases No. 3, 4, and 5 was amended to include the following:

1. That S-HTS glass shall have a minimum average tensile strength of 600,000 psi, as determined by 100 percent sampling of the spools;

2. That glass shall be wound on spools with a lead waywind;

3. The weight of glass per spool shall be between 12.5 and 15 pounds;

4. Test data on the individual breaking loads and yield strength (gm/yd/end) for each test shall be furnished by the supplier.

During the interval between the fabrication of cases No. 2 and 3, Allison investigated ways of improving the fiberglass transfer tensioning system used with winding equipment for fiberglass cases. They compared their existing system (Stevens Brake) with systems from the Compensating Tension and Control Co, Irvington, N.J. (CTC) and Eastern Equipment and Controls Co, Roselle, N.J. (Eastern Brake).

The CTC and Eastern Brake systems were evaluated by feeding glass fiber onto a winding mandrel under tension of 0.2 to 0.9 lb per end, at feed rates up to 350 ft per min, and with a deceleration force of 0.2 gram. The maximum variation in tension using the CTC system was 0.5 lb on a 12 end roving. The Eastern Brake system provided similar results. The maximum tension variation using the Stevens Brake system was 5.0 lb on a 12 end roving (ten times greater than the CTC or Eastern Brake systems). The CTC system maintained more uniform tension and eliminated three transfer rollers from the glass transfer system. Allison purchased and installed 12 CTC glass transfer tensioning systems prior to fabricating case No. 3.

3. Test

The instrumentation and hydroburst testing of TU-290 case No. 2 was conducted at Allison and is described below.

a. Test Preparation

The instrumentation arrangement and measurement devices used for case No. 2 (Figure 19) were identical to those used for case No. 1 except that two additional

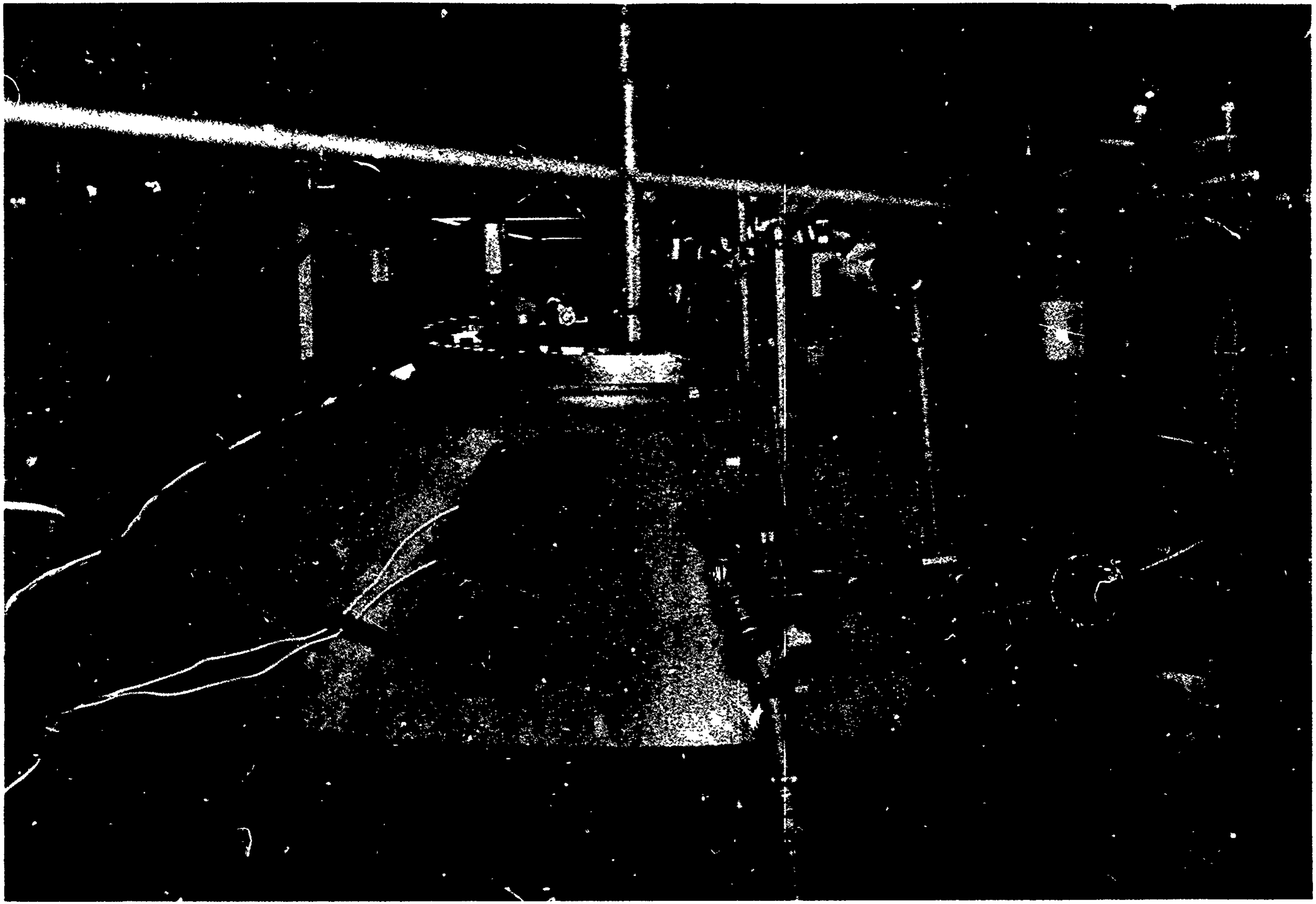


Figure 19. TU-290 Case No. 2 Hydroburst Test Instrumentation

potentiometers were installed on the aft skirt to record the aft skirt movement with respect to the case.

L & N strip charts and a CEC oscillograph recorder were again used to continuously record the longitudinal and radial case deflections. The case noises resulting from resin cracking were monitored by a single contact microphone mounted on the aft dome of the case.

The case was mounted in the test stand in a vertical position and supported on the forward skirt. A sleeve and piston were mounted in the nozzle port to transmit pressure from within the case to the skirt. Linear variation of pressure load, up to 71,300 lb thrust against the forward skirt at 792 psig case pressure, was provided at the nozzle port. A valve relieved the loading to maintain constant pressure at 660 psig. Water was pumped into the case through the port in the forward dome. Because insufficient water volume prevented application of programed test pressures to case No. 1, two pumps were added to the system. The pressure relief valve could be blocked off to permit pressurization above 792 psig to the burst limit.

b. Test Program

The hydroburst test of TU-290 case No. 2 was conducted to further demonstrate structural integrity of the case design and to evaluate S-HTS fiberglass as a case fabrication material. A burst pressure of 792 psig and a hoop fiber stress of 400,000 psi were predicted for the case.

The test program specified (1) a pressure check at 50 psig for 300 sec to condition instruments and verify case integrity, (2) a linear pressure increase to 660 psig in 30 sec to test the case for growth and expansion, (3) a sustained pressure of 660 psig for 60 sec to test the case at proof strength, and (4) a linear increase in pressure until the case failed. This test program is illustrated in Figure 20.

c. Case Testing

While the internal case pressure was being increased to 50 psig for the pressure check, cracking noises (the same as in case No. 1) were heard. The noises ceased while the pressure was held steady for 300 sec and began again as the pressure was increased linearly toward the proof pressure of 660 psig. Steady cracking was sustained for only 12 sec as compared to 25 sec during the first test. This noise reduction was attributed to the improved water pumping system and the increased rate of water pressure application. As in the first test, steady cracking ceased at about 50 percent of burst strain. Intermittent cracking stopped and the case noises became almost inaudible at about 70 percent of maximum burst strain.

The case failed 5 sec after the internal case pressure leveled off at 660 psig. At the time of the failure, the pressure buildup was only 10 sec behind the programed

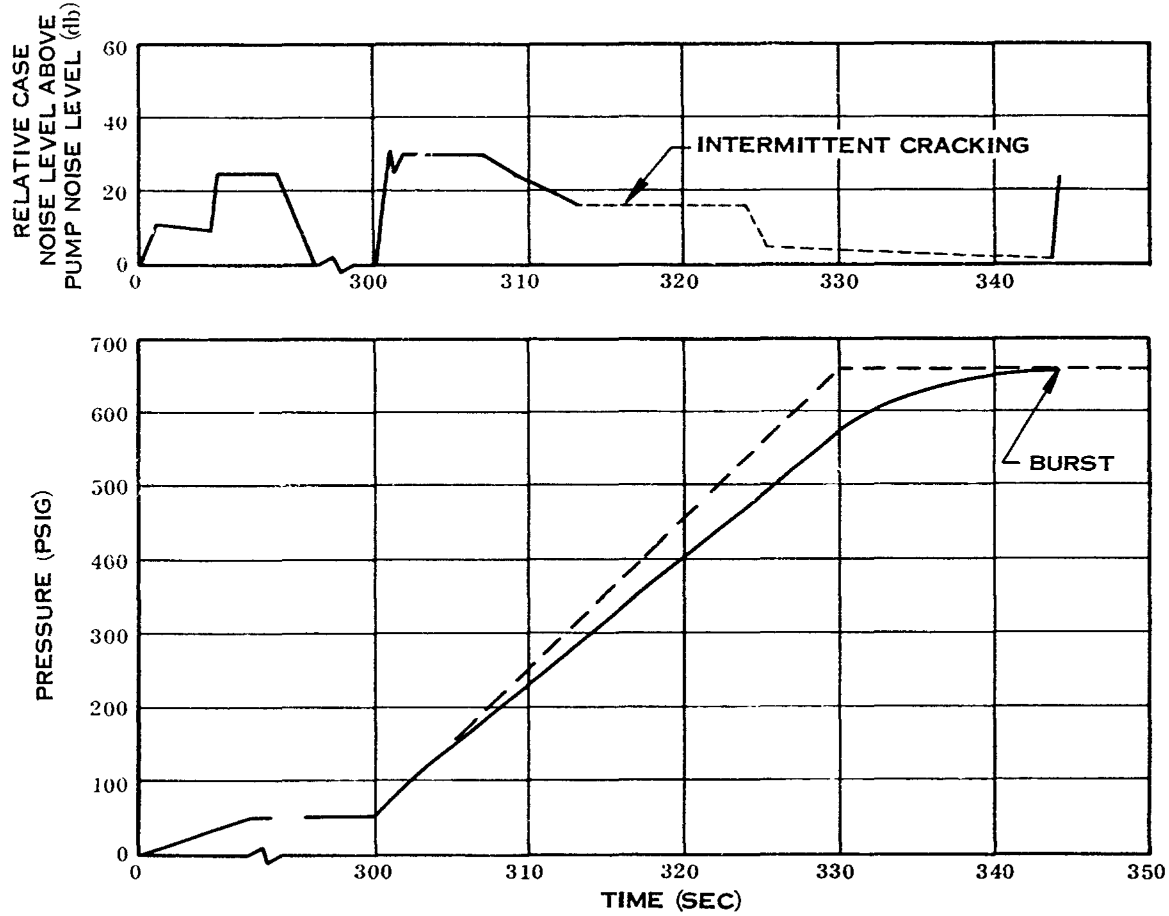


Figure 20. TU-290 Case No. 2 Hydroburst Test Pressure Record

pressure buildup (Figure 20). The failure began in a circumferential crack produced by the separation of hoop windings near the forward tangent line. The same nonlinear deflections recorded for stations 9 thru 11 on the aft dome of case No. 1 were recorded also on case No. 2 (Figure 21). These deflections were attributed to an undefined deflection characteristic of the dome. The early failure of several strain gages (No. 4, 6, 7, and 10; Figure 22) was attributed to severe circumferential cracking of the resin in the hoop windings. The forward dome pole cover plate shear lip failed (Figure 23) either during, or immediately following, the hydroburst test. The lip was found to be separated (for approximately 75 percent of the circumference) from the cover plate.

Pertinent test data for TU-290 case No. 2 are summarized below.

Burst pressure (psig)	660
Design wall thickness (in.)	0.098
Actual wall thickness (in.)	0.097
Ultimate strength (PR/t; psi)	150,250
Maximum hoop fiber stress (psi)	350,500

4. Evaluation and Analysis

The case failure (at 660 psig) was approximately 17 percent below the design burst pressure of 792 psig. During the post test analysis, Allison confirmed the observation that the fiberglass diameter was only 0.00036 in. instead of 0.00037 inch. (The smaller dimension was used in design calculations based upon the Owens-Corning quotation.) The smaller diameter reduced the value for glass content in the case by 6.25 percent.

The case design was re-evaluated, using the lower value for the glass diameter, and a new burst pressure value was computed (725 psig). Using 725 psig as the burst pressure, the actual burst pressure of 660 psig was only 9 percent low. This 9 percent difference was attributed to the glass fiber fraying and breaking which occurred during the fabrication of case No. 2. The fraying and breaking problem was eliminated for future cases by changing the waywind direction from lag to lead on the spools of S-HTS glass.

While the failure of the shear lip did not cause ultimate strength failure of the cover plate nor loss of case pressure, the forward polar fitting was permanently deformed due to imposed stresses above yield strength after shear lip failure (Figure 24).

The designs, fabrication techniques, materials, and hydroburst data for cases No. 1 and 2 were thoroughly evaluated and analyzed at the end of the case No. 2 effort. This evaluation and analysis showed that the basic designs, techniques,

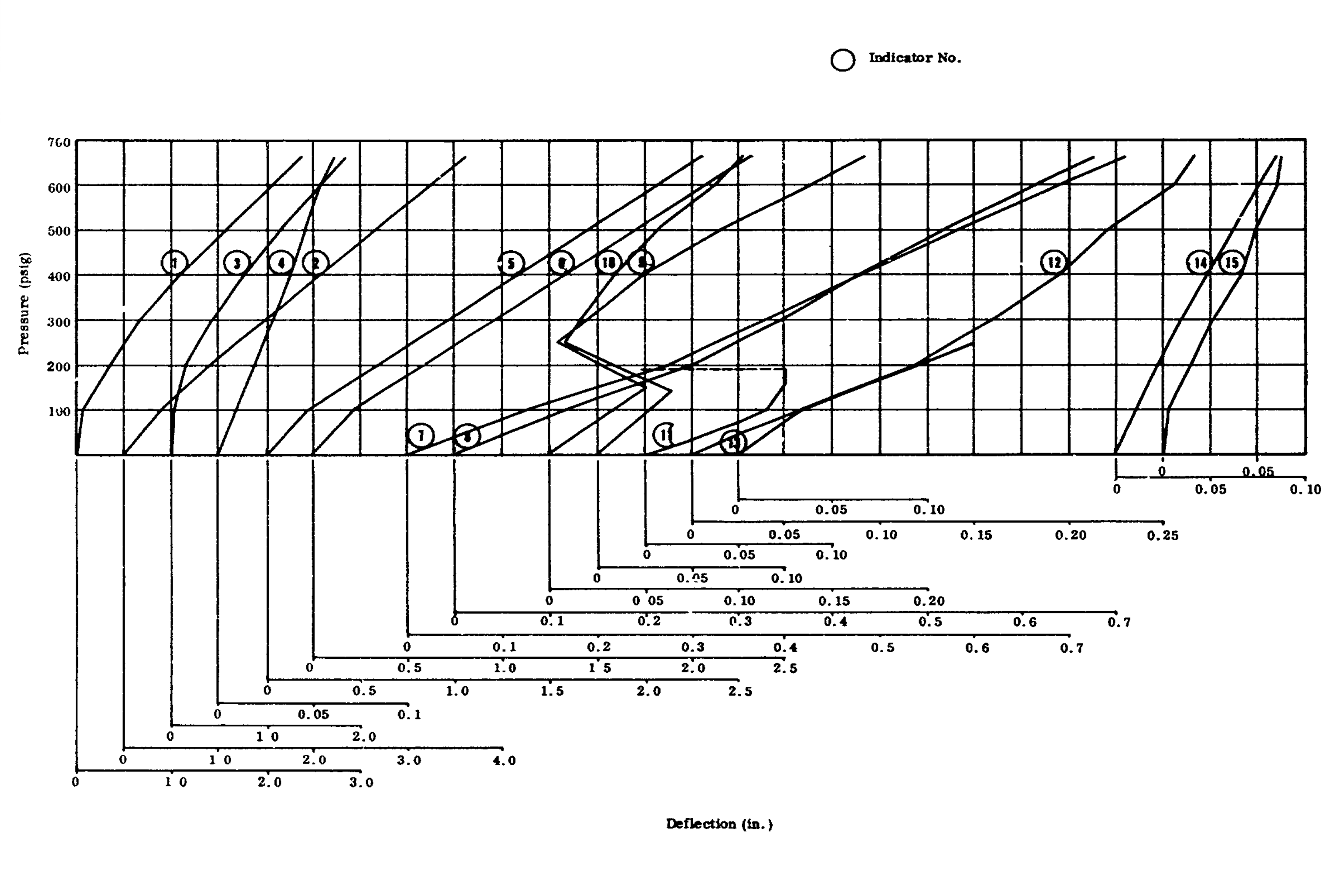


Figure 21. TU-290 Case No. 2 Hydroburst Test Deflection Indications

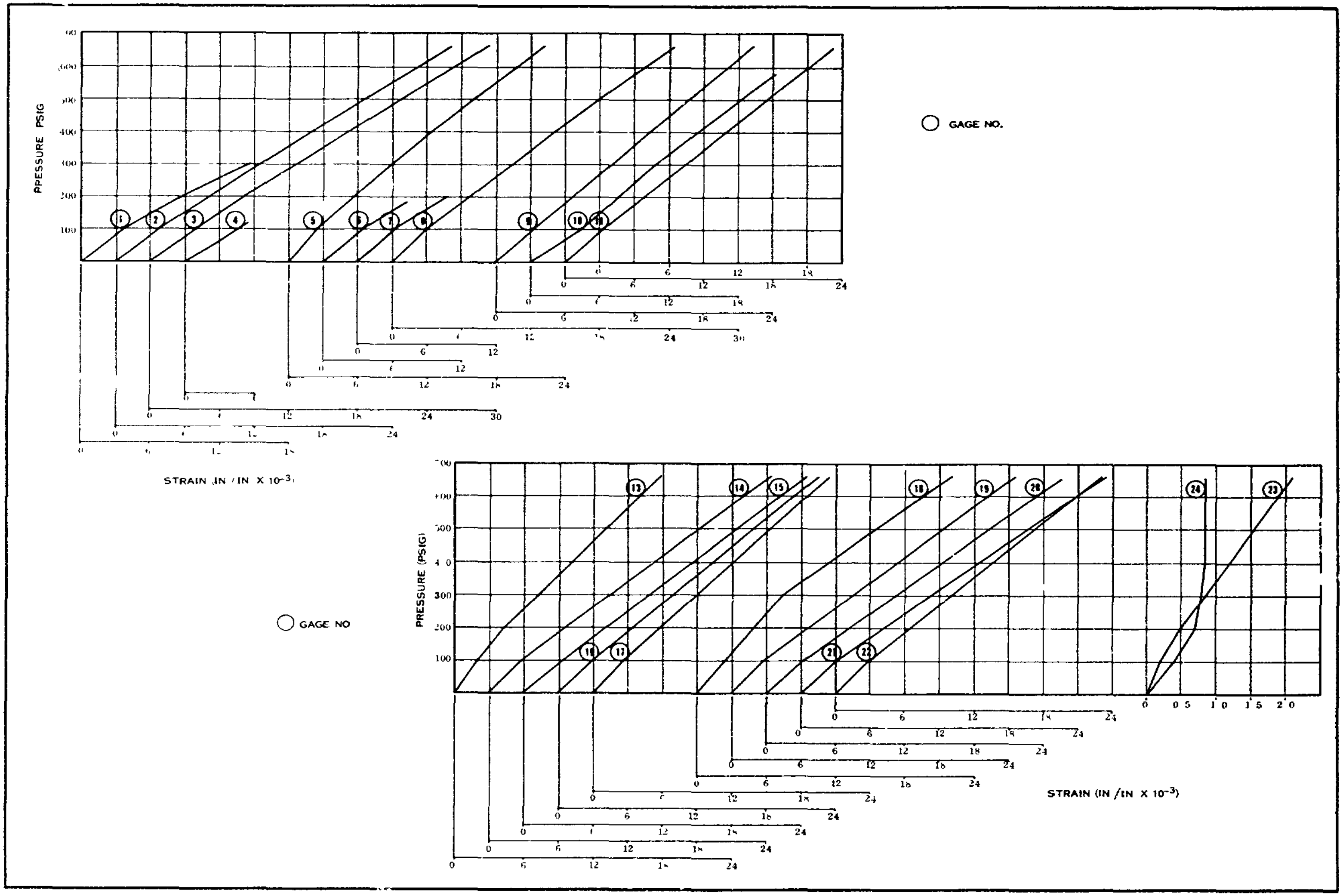
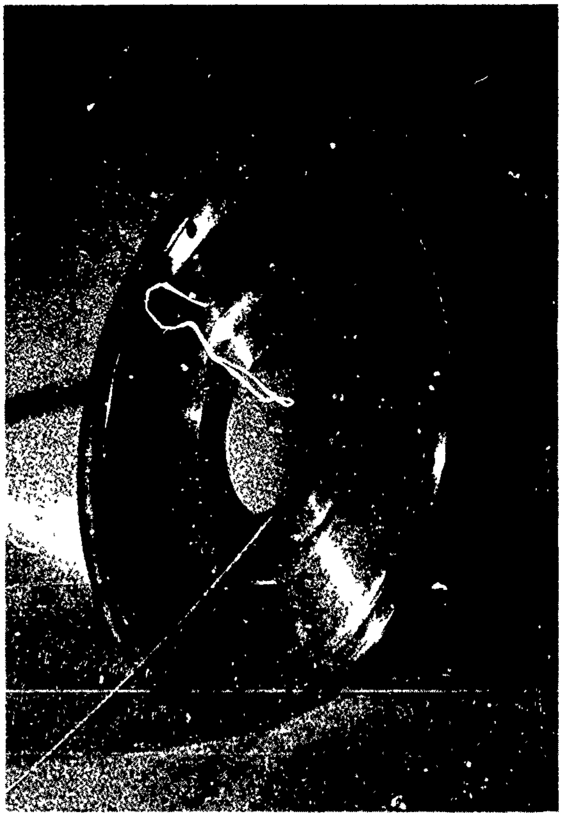


Figure 22. TU-290 Case No. 2 Hydroburst Test Strain Indications



FORWARD COVER PLATE
SHEAR LIP FAILURE

SHEAR LIP FAILURE
DETAIL

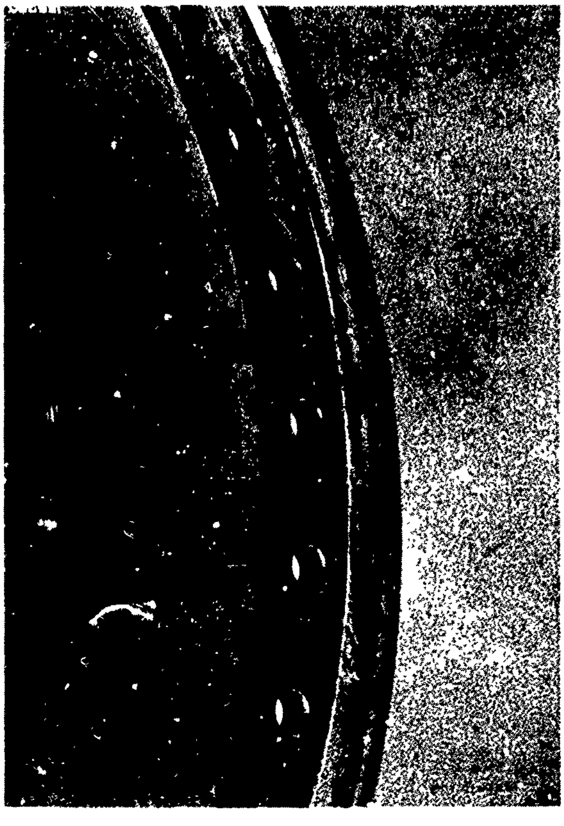


Figure 23. TU-290 Case No. 2 Cover Plate Shear Lip Failure

and materials for the TU-290 case were sound and would produce a case that would meet the program requirements for Phase III of the contract.

The evaluation and analysis also showed that a number of minor design and fabrication changes were necessary before case No. 3 could be fabricated. These minor changes are mentioned below and discussed in detail under the case No. 3 effort.

1. The case design parameters must be modified to account for the reduced glass filament diameter of 0.00036 inch.
2. The band width, band advance, and number of layers must be changed to correspond with the smaller glass filament diameter.
3. The PYROGEN igniter cap must be redesigned to prevent the shear lip from cracking.
4. Methods of adjusting case growth and skirt restraint to prevent premature failure in the case-dome-skirt area must be studied and included in the design of case No. 3.
5. The material acceptance specification for S-HTS glass must be amended to prevent glass fraying and tensile strength difficulties encountered with S-HTS glass for case No. 2.
6. The release agent between the case liner and plaster on the wrapping mandrel must be improved to eliminate the mandrel removal problems experienced with cases No. 1 and 2.
7. The new tensioning systems for fiberglass transfer should be installed in the winding machine to stabilize tension on fiberglass filaments at lower values, before fabrication of case No. 3.

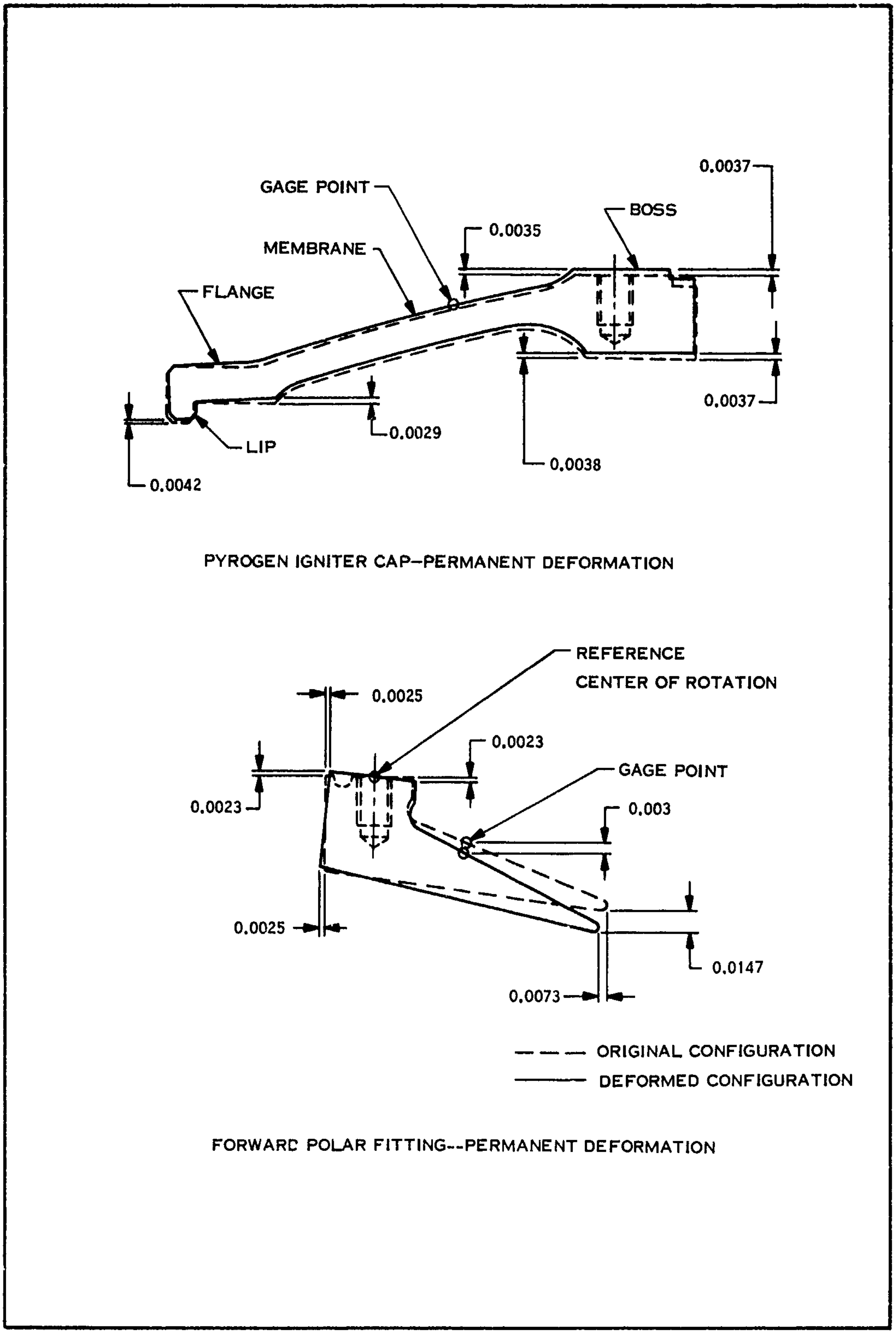


Figure 24. TU-290 Case No. 2 Polar Fitting Deformation

D. TU-290 CASE NO. 3

1. Design

The fabrication, hydroburst test, and analysis of TU-290 cases No. 1 and 2 showed that a number of small, but important, design and fabrication changes were needed before case No. 3 could be fabricated. These design changes involved:

1. S-HTS glass;
2. Glass tensioning systems;
3. Case hardware;
4. Skirt attachments;
5. The winding mandrel.

a. S-HTS Glass

The design of the TU-290 case was modified to accommodate a glass filament diameter of 0.00036 in. instead of 0.00037 inch. The band width, band advance, and number of glass layers were also changed to correspond with the smaller glass diameter. In addition, the wrapping path for the glass filaments was changed to eliminate some filament contact points.

b. Glass Tensioning System

The winding equipment at Allison was modified by replacing existing strand tensioning systems with systems built by Compensating Tension and Control Co (CTC). The new systems maintained more uniform tension, with much less tension on glass strand, as the strand is fed onto the case mandrel.

c. Case Hardware

The PYROGEN igniter cap adapter and forward polar fitting were redesigned to increase the thickness of the shear lip, increase the flange thickness, and provide a larger fillet radius between the shear lip and body. This redesign increased strength and reduced stress concentrations in the igniter cap, without altering margins of safety. (See Volume VI, "Stress Analysis.")

d. Skirt Attachment

The skirt-case-dome juncture must withstand flight loads under all conditions from zero to ultimate design burst limit pressure. The skirt and case, under pressurization, do not expand at a common, constant rate, even though they are bonded

together in a monolithic construction at the juncture. The greater rate and amount of case radial growth imposes increasing compressive stress on the juncture under increasing hoop restraint of the skirt. When the stress becomes sufficiently severe, for any case design, the juncture must inevitably rupture. The design problem was to maintain the skirt diameter large enough to avoid severe stress while the case was under pressure, and also to maintain an integral bond while the case was not pressurized.

To overcome the design problem, a shear ply (a thin sheet of Buna-N rubber) was added between the inside skirt diameter and the helical windings of the case.

Calculations based upon expected strains in the helical laminate of the skirt attachment zone indicated that the axial shear elongation of the rubber sheet should be 0.060 in. minimum to prevent the hoop laminate from separating at the trailing edge of the skirt. The unvulcanized Buna-N rubber sheet was to be applied to the skirt mandrel and cured while the case resin system was being cured.

e. Winding Mandrel

The parting mechanism used to separate the case liner from plaster on the mandrel was changed to simplify mandrel removal. A layer of RTV rubber 0.005 in. thick and a 0.005 to 0.10 in. layer of General Tire and Rubber Co C-41 noncuring adhesive were applied to the mandrel. The V-45 case liner was wrapped over this layer of rubber. Seams were sprayed with V-57 sealant.

2. <u>Fabrication</u>

Twelve spools of S-HTS glass with a lead waywind were received from Owens-Corning for case No. 3. The average strand tensile strength for the spools was 660,000 psi (60,000 psi above the acceptance standard established by Allison at the end of the case No. 2 effort).

Before the skirts and case were fabricated, the design modification for the skirt (i.e., a sheet of Buna-N rubber to absorb case growth stress) was evaluated. A new discontinuity analysis (Volume VI) for the dome-skirt-cylinder juncture was developed to evaluate this rubber separator. The analysis was based upon the following assumptions:

1. Hoop strain in the helical laminate of the case was the same as hoop strain in the skirt-case hoop laminate;
2. Axial strain in the helical laminate of the case in the region of skirt attachment was independent of axial strain in the skirt-case hoop laminate.

Using these assumptions (which pertain to thin rubber membranes only), discontinuity stresses and established dome contours were independent of the thickness or shape of the rubber separator. The preliminary contour and stress analysis indicated that:

1. Discontinuity stresses in the aft dome were decreased and discontinuity stresses in the forward dome were increased;
2. Discontinuity stresses in the aft and forward domes were less than those in the aft dome of case No. 2;
3. The very slight dome contour changes produced by this analysis did not warrant a change in the design drawings.

Two tests were performed to establish the number of layers of 0.030 in. rubber, required. First, a single thickness of 0.030in. rubber was applied between the skirt, case, and dome. A total shear elongation of 0.020 in. over the desired axial attachment length was measured. Second, two thicknesses of 0.30 in. rubber were applied. A shear elongation of 0.059 in. was measured. Since the 0.060 in. total axial shear elongation was the minimum indicated requirement, three thicknesses of 0.30 in. rubber were used. The three sheets had varying axial lengths to provide a tapered cross section of the membrane.

a. Skirt Fabrication

The redesigned skirts for case No. 3 were wound, partially cured, and partially machined without incident. Skirt removal procedures previously successful (contracting the mandrel with dry ice) were unsuccessful for the redesigned skirts. The difficulty in removing the mandrel was attributed to the Buna-N shear ply in the skirts. To reduce the radial loads and friction effects between the rubber shear ply and skirt mandrel (to release the mandrel) the skirts were cured for 4 hr at 325°F. Following the cure, the skirts still could not be removed by conventional methods. The magnesium skirt mandrel was then cut into sections and removed. The mandrel was cut to permit reassembly for cases No. 4 and 5.

b. Case Fabrication

Case No. 3 was successfully wound with S-HTS glass without difficulty. The filament fraying and breaking problem of case No. 2 was not encountered. Winding equipment was equipped with the new strand tensioning systems.

After case No. 3 was cured, the mandrel was removed successfully from the case and the case was mounted on a dolly for transfer to the hydroburst test area. The design weight and actual weight of the case are compared in Table IV.

3. Test

Instrumentation and hydroburst testing of TU-290 case No. 3 was conducted at Allison.

a. Test Preparation

Measurement indicators were applied to case No. 3 in the same basic arrangement as for cases No. 1 and 2, except for a single microphone contact (instead of three) near gage 17, for re-arrangement of gages 14 and 15 to measure strain on case and skirt in the region of the rubber layer, and for special instrumentation (Figure 25) to measure strain on the redesigned forward polar fitting.

The case was mounted in the test stand in a vertical position and supported on the forward skirt. A sleeve and piston were mounted in the nozzle port to transmit pressure from within the case, through the test stand frame, to the forward skirt. For previous TU-290 case hydroburst tests, a pressure load from zero to 71,300 lb, which varied linearly with case pressure up to 792 psig, could be applied to the forward skirt. Water was pumped into the case through the port in the forward dome. The pressure relief valve was set to sustain case pressure at 660 psig, and after the holding period at 660 psig was completed, the pressure relief valve was blocked to permit increase of pressure until the case burst. For the TU-290 case No. 3, to which the conditions just stated pertain, a preselected volume and flow rate were established for the pumps, which were based on expansion measurements of the previous cases.

b. Test Program

The hydroburst test of TU-290 case No. 3 was conducted as a final evaluation of the case design and to complete the evaluation on S-HTS fiberglass as the case material. A burst pressure of 792 psig and hoop fiber stress of 400,000 psi were again predicted for the case.

The test program (Figure 26) specified (1) a pressure check at 50 psig for 300 sec to condition the instrumentation and to establish case integrity, (2) a linear pressure increase to 660 psig in 30 sec to test the case for growth and expansion, (3) a proof pressure check at 660 psig for 70 sec, and (4) a linear pressure increase until case rupture (Figure 27).

TABLE IV

TU-290 CASE NO. 3 WEIGHT SUMMARY

Item	Design Weight (lb)		Actual Weight (lb)	
Fiberglass	132.2		133.5	
Skirts	21.3		23.4	
Case liner	50.0		49.0	
Elastomer	2.3		0.0	
Polar fittings	16.7		17.1	
Threaded inserts	0.2		0.0	
Subtotal, case assembly		222.7		223.0
O-ring seal	0.1		0.1	
PYROGEN igniter cap	9.7		10.0	
Spacer sleeve	0.3		0.3	
Bolts	1.4		1.3	
Threaded inserts	0.1		--	
Total, case assembly		234.3		234.7

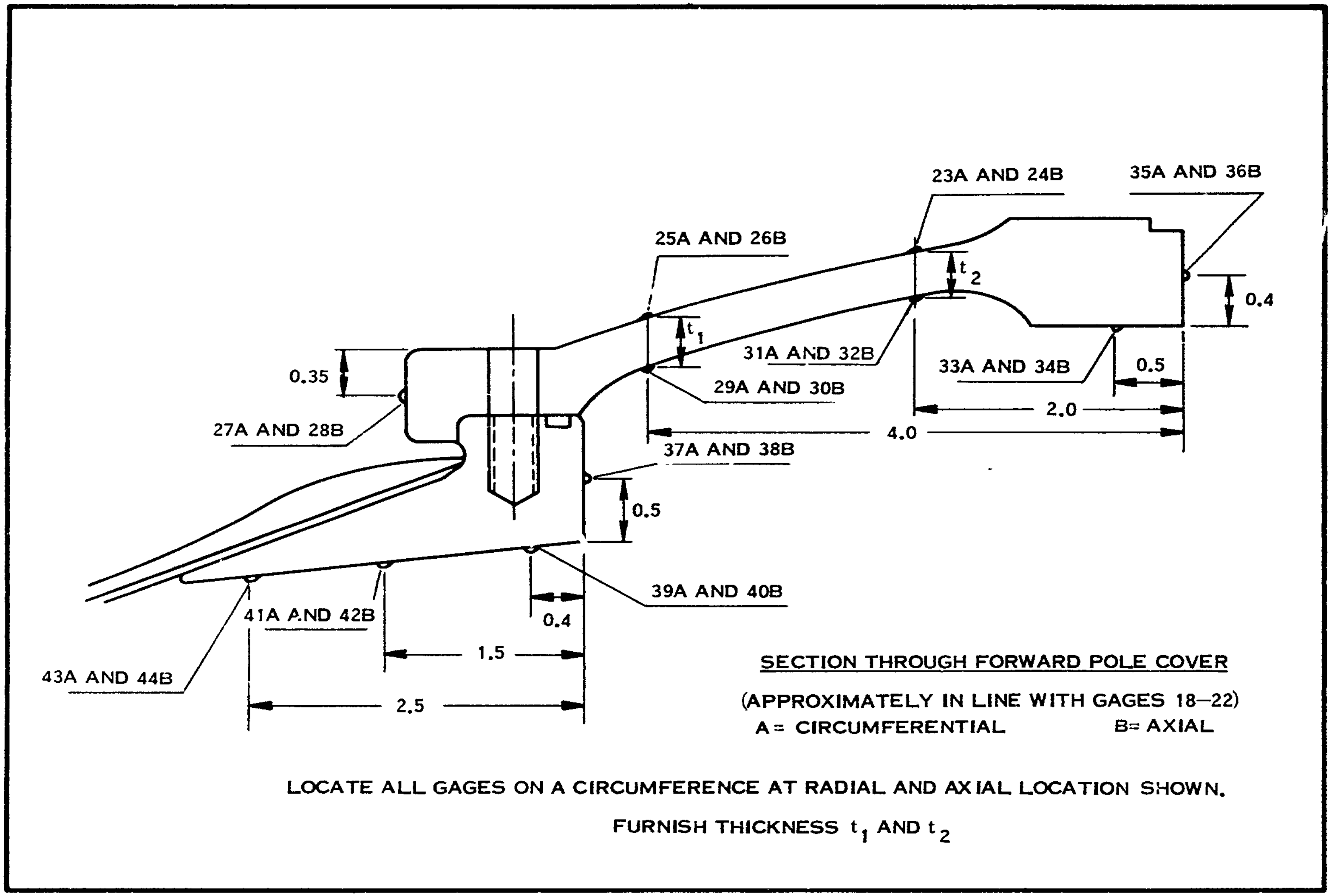


Figure 25. TU-290 Case No. 3 Hydroburst Test Strain Gage Arrangement - Forward Polar Fitting

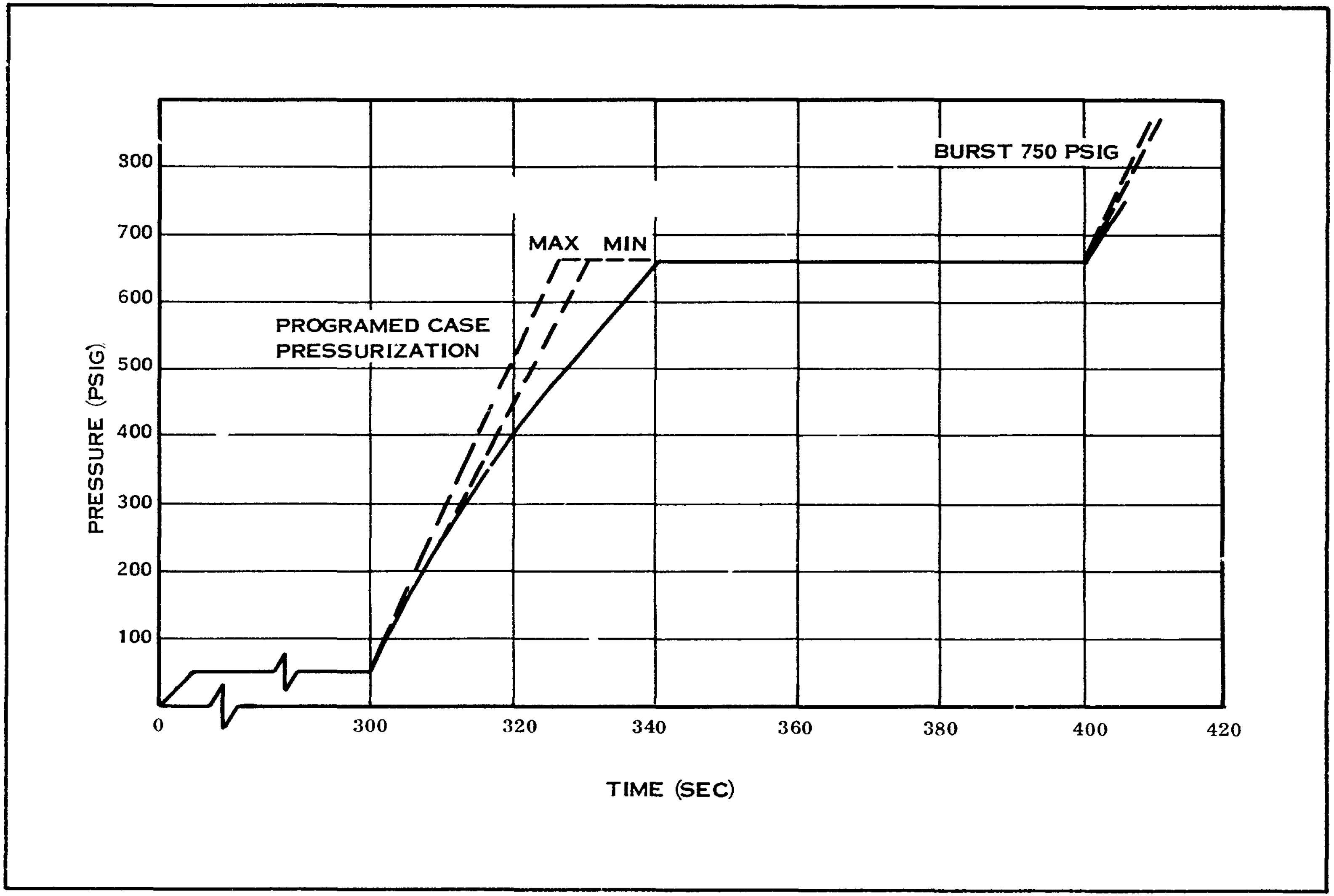
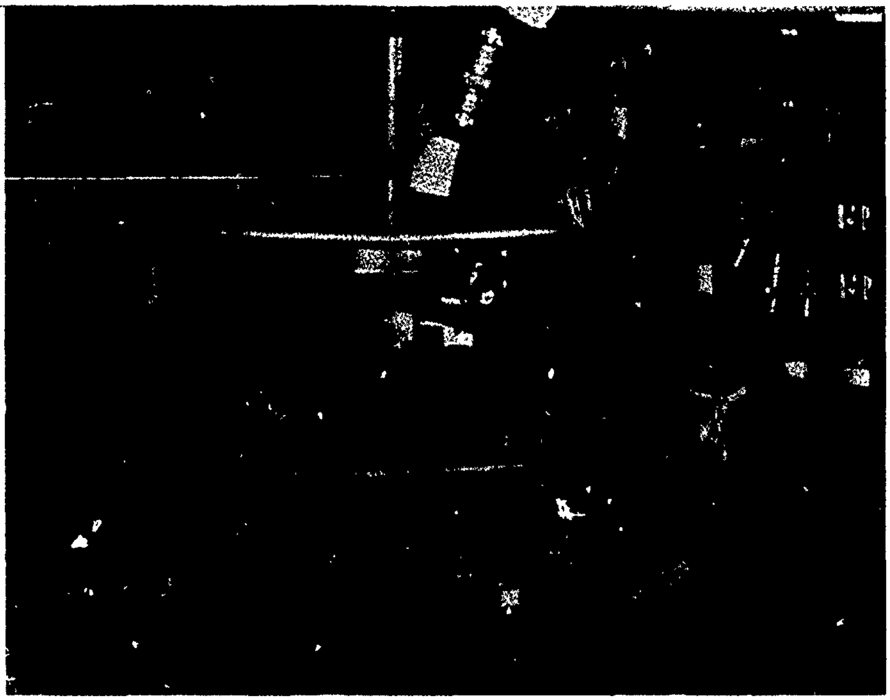


Figure 26. TU-290 Case No. 3 Hydroburst Test Pressure Record



TU–290 Case No. 3
in Hydrotest Facility

TU–290 Case No. 3
Aft Rupture

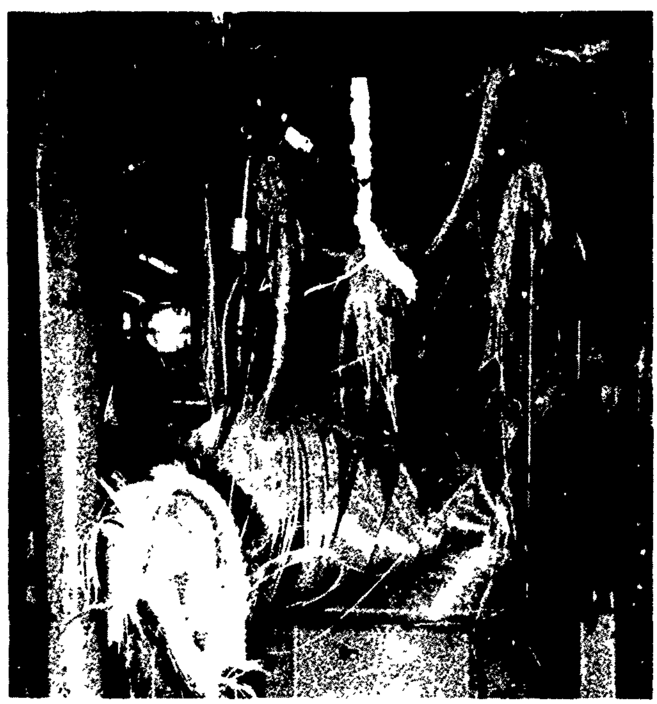


Figure 27. TU-290 Case No. 3 Hydroburst Test

c. Case Testing

Case cracking noises were rapid during the first 20 sec of the pressure check, but ceased, except for a few sporadic individual cracks, thereafter. Rapid cracking began again with the increase of pressure and ceased between 40 and 50 percent of burst strain. Minor cracking occurred until 80 to 90 percent of burst strain was reached. The case was monitored through a single contact microphone located near gage 17.

Nonlinear deflections were again recorded at extensometer stations 9 through 11 on the aft dome. These deflections were similar to those noted in cases No. 1 and 2, which further indicated the presence of a peculiar deflection characteristic in the dome. Figure 28 shows the deflection and strain measurements for the hydroburst test.

The test program was successfully completed up through and including the proof pressure check at 660 psig for 60 seconds. Case failure occurred at 750 psig. The failure started in a circumferential crack in the aft tangent area. Film coverage (64 and 500 fps) of the burst showed that the failure started at the edge of the aft skirt. Strain gages located in the area of failure indicated that the hoop laminate separated at the forward edge of the aft skirt at approximately 400 psig (Figure 29).

The hydrostatic piston load force, which was reacted by the forward skirt to the test frame, offset the tendency of the forward skirt to move with the dome growth. As a result, separation did not occur in the hoop laminate at the trailing edge of the forward skirt.

Pertinent test data for the third TU-290 case are summarized below.

Burst pressure (psig)	750
Ultimate strength (PR/t; psi)	161,000
Maximum hoop fiber stress (psi)	379,000
Design wall thickness (in.)	0.105
Minimum actual wall thickness (in.)	0.103

4. Evaluation and Analysis

Changing the waywind direction from lag to lead on the spools of S-HTS glass used for case No. 3 completely eliminated the strand fraying and breaking problem encountered with case No. 2. The hoop fiber strength was 8 percent higher than for case No. 2, primarily because the S-HTS glass was fed onto the case wrapping mandrel without damage. The new CTC tensioning systems also contributed to the increased strength of case No. 3.

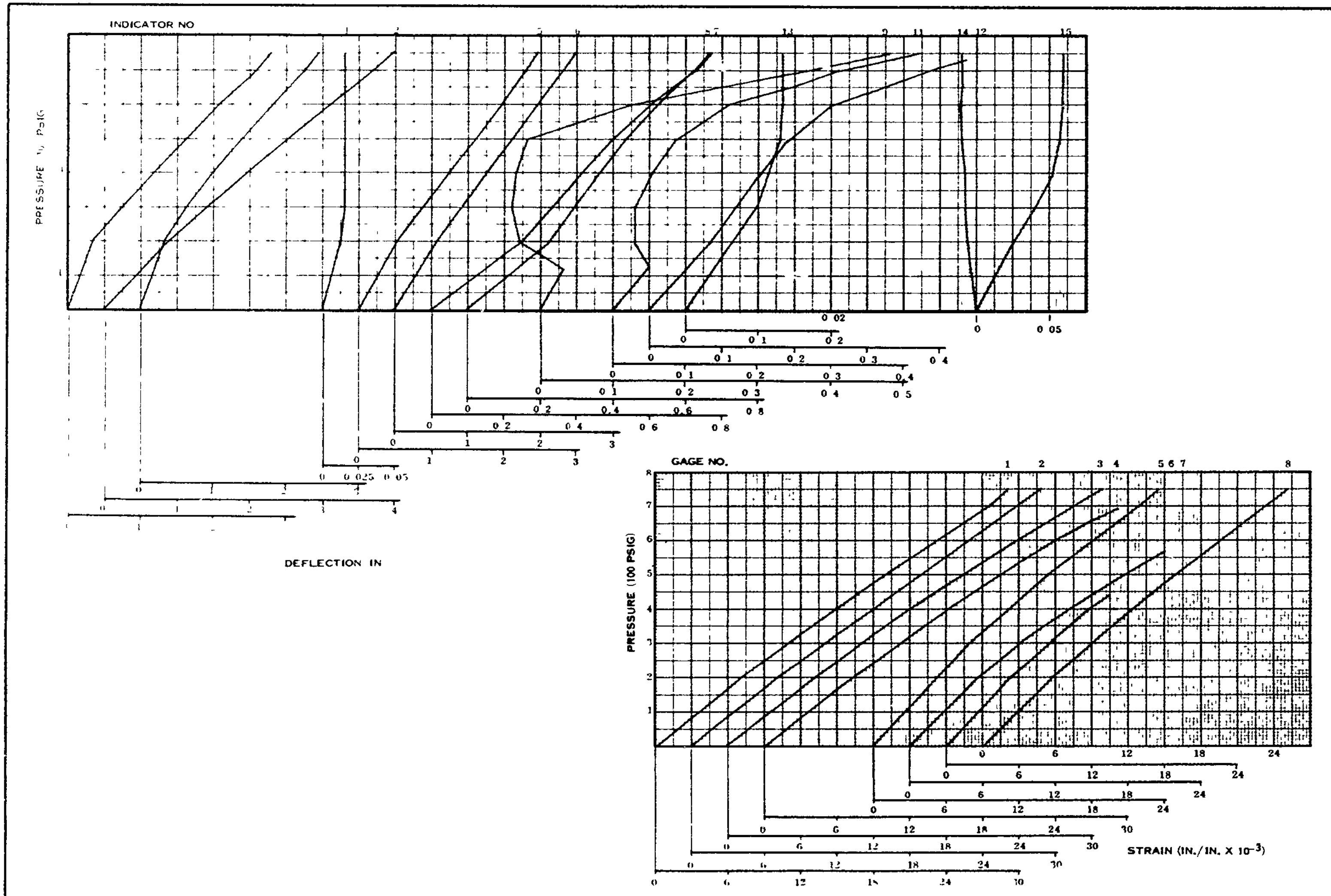


Figure 28. TU-290 Case No. 3 Hydroburst Test Deflection and Strain Indications

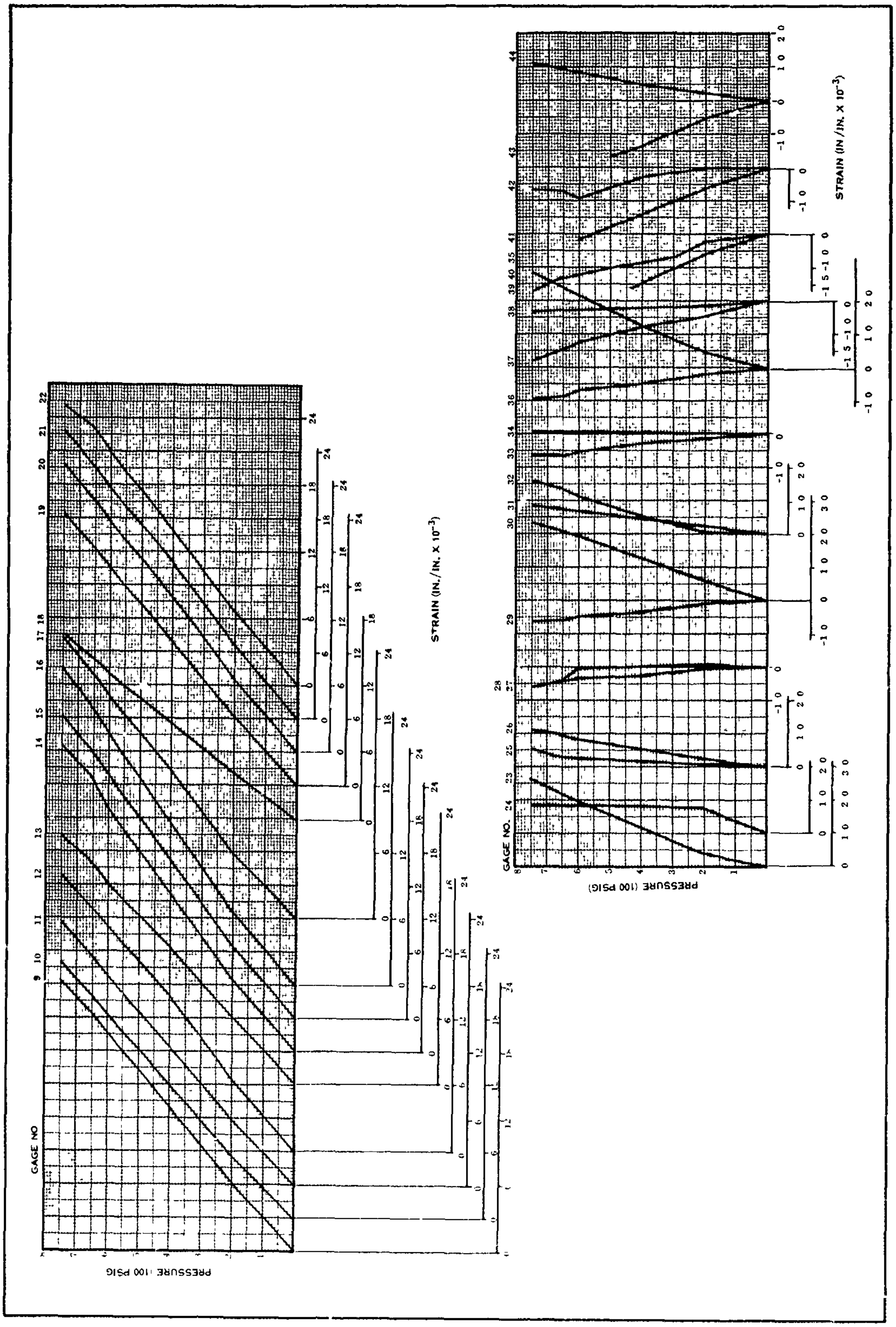


Figure 29. TU-290 Case No. 3 Hydroburst Test Strain Indications

Buna-N rubber as a shear ply between the skirt and case helical windings successfully prevented a bond failure in the skirt-dome attachment regions. Fiberglass from the helical windings adhering to the inside of the rubber membrane after the hydroburst test attested to the effectiveness of the elastomeric ply.

After case No. 3 was tested, corrective action to eliminate hoop laminate separation during the case pressurization was investigated. Incorporating a helically wound fiberglass mat at the forward edge of the aft skirt was considered an effective way of preventing the hoop laminates from separating. This design consideration was proposed to the Air Force for inclusion in the design of cases No. 4 and 5.

Although a burst pressure of 792 psig and a hoop fiber stress of 400,000 psi were not attained, the values obtained (750 psig and 379,000 psi) were deemed acceptable to satisfy program objectives (Supplemental Agreement No. 5 to Contract AF 33 (600)-42511, dated 6 June 1963). For cases No. 4 and 5, the proof pressure is established at 550 psig.

E. TU-290 CASES NO. 4 AND 5

1. Design

During the analysis of case No. 3, Thiokol recommended to the Air Force that a helically wound fiberglass mat be placed over the forward edge of the aft skirt to eliminate possible hoop laminate separation in cases No. 4 and 5. Because another development case would have to be fabricated and tested to evaluate this proposed design improvement, the Air Force decided to permit fabrication of two cases identical to case No. 3, with a modified ballistic design to reduce case pressure.

The only design change made to cases No. 4 and 5 was to feather the Buna-N rubber shear ply used between the helical case windings and the skirts. This design change was made to provide a flat surface in the skirt joint area for the hoop windings.

2. Fabrication

With the exception of adding the case insulation to the winding mandrel, cases No. 4 and 5 were fabricated in the same manner as case No. 3. Actual weights and dimensions for the two delivery cases are shown in Table V.

A pre-proof test inspection of case No. 4 showed that the aluminum pole pieces had warped out of dimensional tolerance during the case curing. The cover plates were reworked to fit and the case was inspected and accepted for hydroproof testing.

The aluminum pole pieces on earlier cases had shown similar dimensional change, but not to the extent of being out of tolerance. The aluminum pole pieces for case No. 4 were heat treated to 250° F before case assembly, but curing of the case assembly at 350° F relieved stresses developed during assembly and changed the dimensions of the pole pieces.

The aluminum pole pieces for case No. 5 were already fabricated and in position on the case mandrel when the above problem was discovered with case No. 4. Since the pole pieces may have remained within tolerances during the cure of case No. 5, no action was taken. Case No. 5 was wound and cured without difficulty, inspected, and accepted for hydroproof testing.

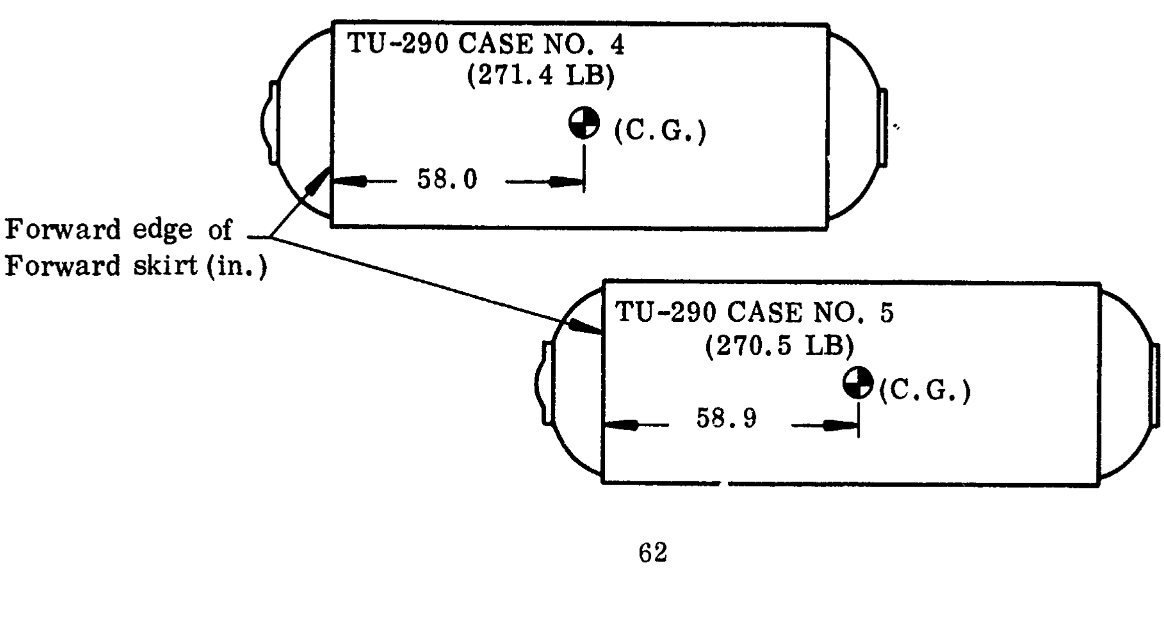
3. Test

TU-290 cases No. 4 and 5 were successfully hydroproof tested at 550 psig for 60 seconds. Following the tests, the cases were packaged for shipment and forwarded to Thiokol for bonded storage.

TABLE V

TU-290 CASES NO. 4 AND 5 WEIGHT SUMMARY

Item	Design Weight (lb)		Actual Weight Case No. 4 (lb)		Actual Weight Case No. 5 (lb)	
Fiberglass	132.2		144.7		142.8	
Skirts	23.3		25.3		23.4	
Case liner	30.7		27.2		28.0	
Insulation	48.6		45.5		47.8	
Polar fittings	16.7		17.2		17.4	
Subtotal, case assembly		251.5		259.9		259.4
O-ring seal	0.1		0.1		0.1	
PYROGEN igniter cap	9.8		9.9		9.5	
Bolts	1.6		1.5		1.5	
Total, case assembly		263.0		271.4		270.5



F. TU-290 ROCKET MOTOR DESIGN

1. Ballistic Design

The preliminary ballistic design for the TU-290 motor was started and completed during the fabrication and hydrotest of case No. 2. The design specified a six pointed star configuration using PBAA type propellant. The motor was to contain 11,007 lb of propellant, and to have a mass fraction (excluding igniter) of 0.965 or better.

This preliminary ballistic design was later changed to a slotted cylindrical perforation (CP) grain. The following performance improvements were realized by changing to the slotted CP grain:

1. The propellant strain during motor operation was much less in the CP grain than in the star grain, resulting in a more reliable motor;
2. The characteristic thrust curve for the slotted CP grain was neutral over the entire motor action time while that for the star grain was progressive;
3. The CP grain provided a very short tailoff which minimized propellant sliver loss experienced with the star grain and permitted a greater motor mass fraction.

The performance characteristics of the CP grain were based upon the performance of PBAA type propellant with an average chamber pressure of 500 psia. Table VI summarizes motor weight data.

The conical slots of the CP grain were inclined at 30 deg to the forward and aft tangent lines of the case. Each slot surface was described by the frustum of an equilateral right circular cone whose vertex was on the motor centerline. The forward and aft cone vertices opposed one another. The grain head end web was approximately 90 percent of the thickness of the center section web. The propellant grain extended to the aft dome and was cut back to allow the nozzle to be installed.

Details of the overall motor design are shown in Figure 30. General specifications and performance parameters are presented in Table VII.

Changing to the slotted CP grain required slight modifications to the insulation design for cases No. 4 and 5. Additional V-44 rubber was needed to insulate the dome areas. The thickness of the V-44 rubber in the dome areas was increased, and the

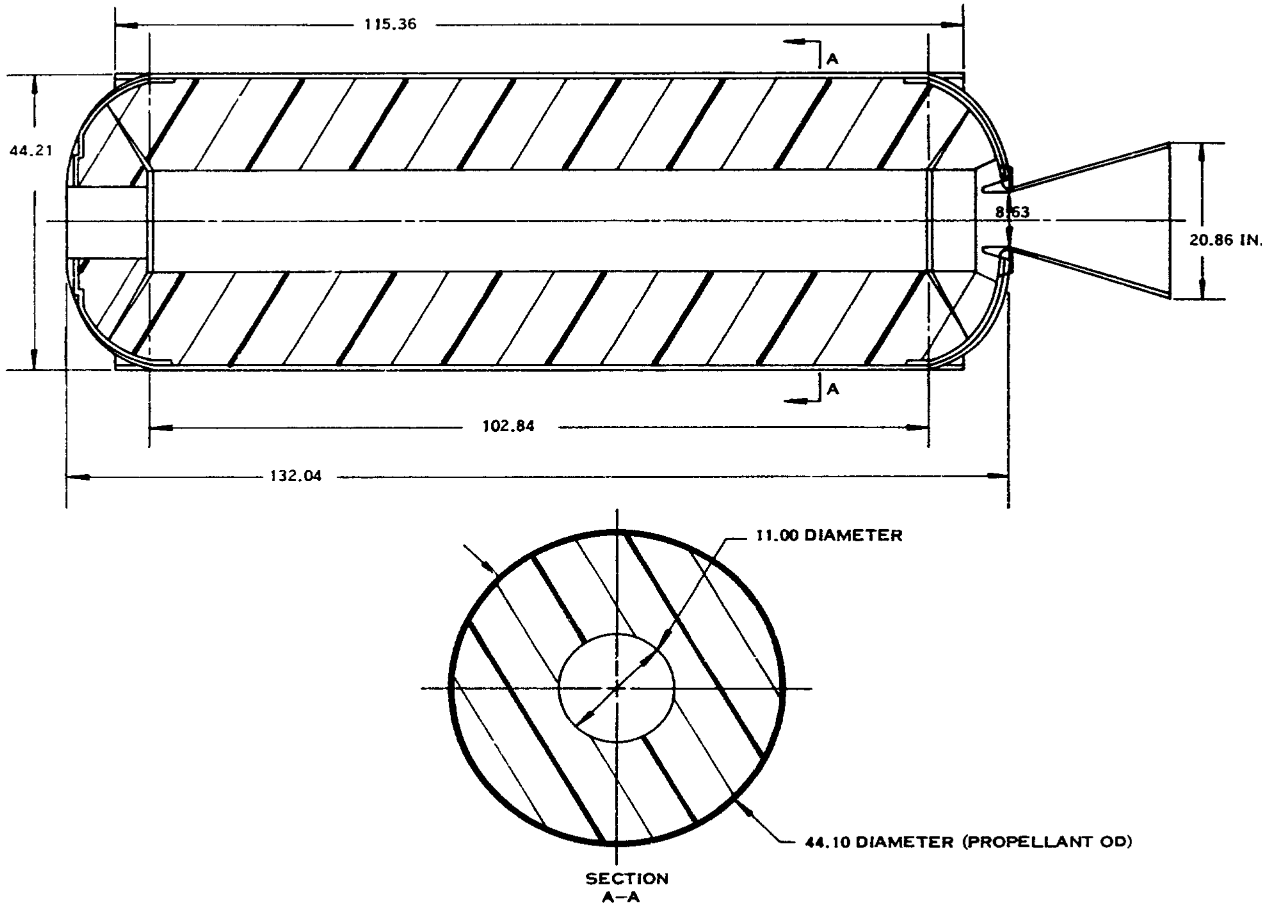


Figure 30. Cross Section of TU-290 Motor Using CP Grain

TABLE VI

TU-290 MOTOR WEIGHT SUMMARY

Component	Case No. 4 (lb)	Case No. 5 (lb)
Case 9U34847-04	271.4	270.5
Nozzle 9U34907	77.2	77.2
MS20002C5 washer	0.2	0.2
NAS625-6 bolt	1.3	1.3
Packing (No. 5-074)	0.1	0.1
Insulation (forward, theoretical)	4.4	4.4
Insulation (aft, theoretical)	6.1	6.1
Inhibitor sleeve (theoretical)	1.5	1.5
Liner activator (theoretical)	6.2	6.2
Propellant (theoretical)	11,016.7	11,023.7
Total weight (theoretical)	11,385.1	11,391.2
Mass fraction $= \frac{\text{Usable propellant weight}}{\text{Total motor weight}}$	0.9674	0.9675

TABLE VII

TU-290 MOTOR GENERAL SPECIFICATIONS

<u>Dimensions (in.)</u>	
Overall motor length	156.9
Case outside diameter	44.21
<u>Weight (lb)</u>	
Case	215
Insulation	50
Ignition system	20
Nozzle	82
Total motor weight	11,456
Mass fraction	0.968
<u>Chamber</u>	
Minimum yield strength, fiberglass (psi)	500,000 (strand test)
Specific weight (lb/cu in.)	0.070
Nominal thickness (in.)	0.103
Hydrotest pressure (psia)	550
Design pressure, 3-sigma limit (psia)	567
<u>Nozzle</u>	
Expansion cone configuration (α in deg)	15
Initial throat diameter (in.)	8.63
Final throat diameter (in.)	9.20
Erosion rate (in./sec on radius)	0.005

split flap was removed. Moreover, the dome insulators were changed to a homogeneous solid part (Figures 31 and 32). Two additional small sections of V-44 rubber were added in the aft and forward ends of the cylindrical section of the case to accommodate end burning in the slotted areas.

The head end of the motor was designed to accommodate a TU-222 PYROGEN igniter.

2. Nozzle Design

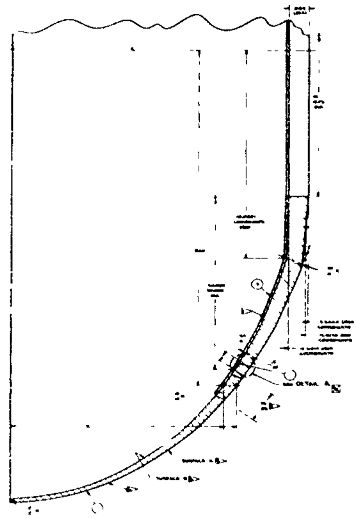
The preliminary nozzle design for the TU-290 motor (Figure 33) was completed and analyzed (see Volume VI for stress analysis) during the fabrication of case No. 2. The nozzle was a partially recessed, fixed, conical nozzle with HLM-85 graphite in the throat.

This design was later modified. The monolithic graphite throat was replaced with three graphite rings (Figure 34). This change was made to accommodate thermal expansion and prevent the HLM-85 graphite from fracturing. The revised nozzle design was submitted to ASD for approval during the fabrication of case No. 3.

During the design review with ASD, additional design modifications were made which were incorporated into an approved design drawing 9U34907 (Figure 35). H. I. Thompson Fiber Glass Co was awarded a subcontract to fabricate two TU-290 nozzles, according to Thiokol Drawing 9U34907 (Figure 35).

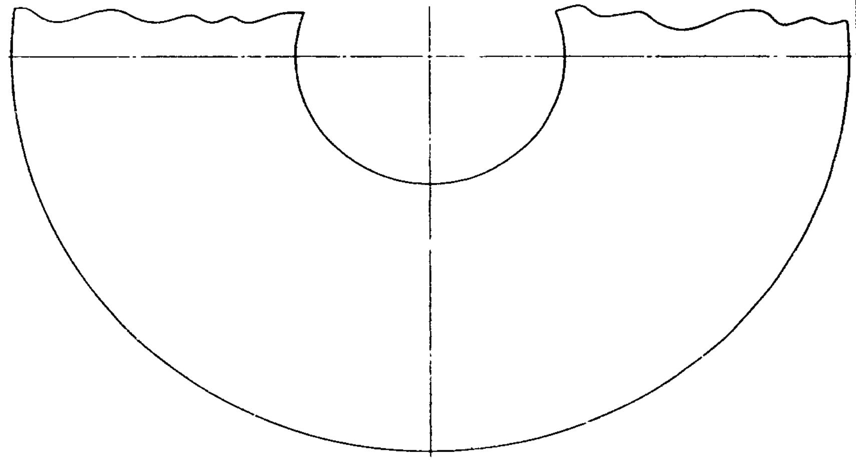
A test, at Thiokol in August 1963, of a nozzle similar in design to that of Figure 35 indicated more erosion in the recessed portion of the nozzle than was anticipated. Using erosion data from this test and plotting a new erosion profile at T + 55 sec showed that the nozzle design was inadequate. The amount of insulating material remaining in the recessed region was found to be marginal for thermal insulation and strength (Figure 36). The nozzle design was modified to place the metal part deeper into the surrounding insulation (i.e., moved 0.2 in. toward the nozzle centerline). The external contour of the recessed section was not changed; only internal mating surfaces were affected by this last change (Figure 37). The insulating material remaining at T + 55 sec was sufficient to protect the metal parts from excessive heat and thus retain its strength values.

Two nozzles for the TU-290 motor, fabricated to the revised drawing 9U34907A (Figure 38) were finished, inspected, and shipped to Thiokol after case No. 5 was fabricated and hydroproof tested.



BASIC COORDINATE TABLE SURFACE A	
X	Y
-.0028	21.9269
+.3948	21.9070
.9911	21.8544
1.5872	21.7732
1.9846	21.7025
2.3819	21.6180
2.9780	21.4649
3.5740	21.2792
3.9713	21.1367
4.3687	20.9789
4.9647	20.7120
5.3621	20.5133
5.9581	20.1821
6.5541	19.8087
6.9514	19.5347
7.3488	19.2392
7.9447	18.7526
8.5406	8.2089
8.9378	17.8112
9.3349	17.3823
9.9305	16.6734
10.5257	15.8741
10.7240	15.5846
10.9223	15.2824
11.1205	14.9665
11.3185	14.6361
11.5165	14.2901
11.7145	13.9273
11.9119	13.5465
12.1093	13.1466
12.3064	12.7261
12.5030	12.2842
12.6991	11.8200
12.8943	11.3338
13.0882	10.8274
13.2800	10.3061
13.9450	8.5000
13.4270	8.5000
13.5464	7.0400

BASIC COORDINATE TABLE SURFACE B	
X	Y
-.0098	21.7270
+.3818	21.7064
.9685	21.6520
1.5542	21.5679
1.9442	21.4948
2.5335	21.[illegible]76
2.9168	21.2495
3.4990	21.0581
3.8863	20.9114
4.2730	20.7491
4.8514	20.4750
5.2360	20.2712
5.8109	19.9321
6.3833	19.5507
6.7633	19.2715
7.1421	18.9708
7.7073	18.4768
8.2689	17.9264
8.6409	17.5248
9.0109	17.0926
9.5616	16.3802
10.1065	15.5795
10.2866	15.2898
10.4660	14.9879
10.6445	14.6727
10.8220	14.3433
10.9987	13.9985
11.1742	13.6373
11.3486	13.2584
11.5219	12.8607
11.6938	12.4424
11.8652	12.0029
12.0338	11.5401
12.2015	11.0546
12.3678	10.5468
12.5329	10.0201
12.6614	7.0400



NOTES:

1. SEPARATOR CLOTH, FILM OR OTHER MATERIAL IN UNVULCANIZED AREA BETWEEN ITEMS 2 & 3, IF USED IN MANUFACTURE OF PART, TO BE REMOVED BY VENDOR.
2. ITEMS 2 & 3 MAY BE PRODUCED AS AN INTEGRAL UNIT OR PRODUCED SEPARATELY AND VULCANIZED IN AREA SHOWN
3. ITEM 1 TO BE INTEGRAL BY VULCANIZATION TO ITEMS 2 & 3. LOCATION OF CIRCUMFERENTIAL BUTT JOINT OPTIONAL.
4. THESE COORDINATES FORM A STRAIGHT LINE.
5. CONTOURS OF SURFACES A & B MAY VARY WITHIN A .020 TOLERANCE BAND PARALLEL TO ℄ CENTERED ON BASIC TABLE DIMENSIONS
6. MARK PART NO. PER TUS-59-33, METHOD 6.
7. GENERAL TIRE & RUBBER CO, AKRON, OHIO.

-01	ITEM NO.	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
AR	3		-04	FLAP	V-45	7
AR	2		-03	INSULATION	V-44	7
[illegible]	1		-02	CLOTH - .005 THK	NYLON	TUS-61-55

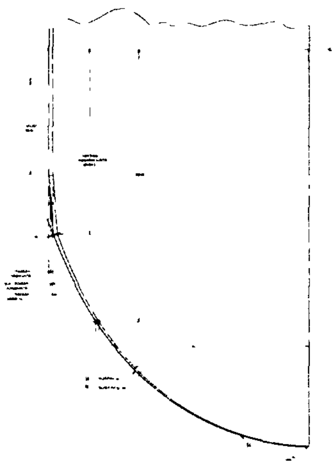
LIST OF MATERIAL OR PARTS LIST

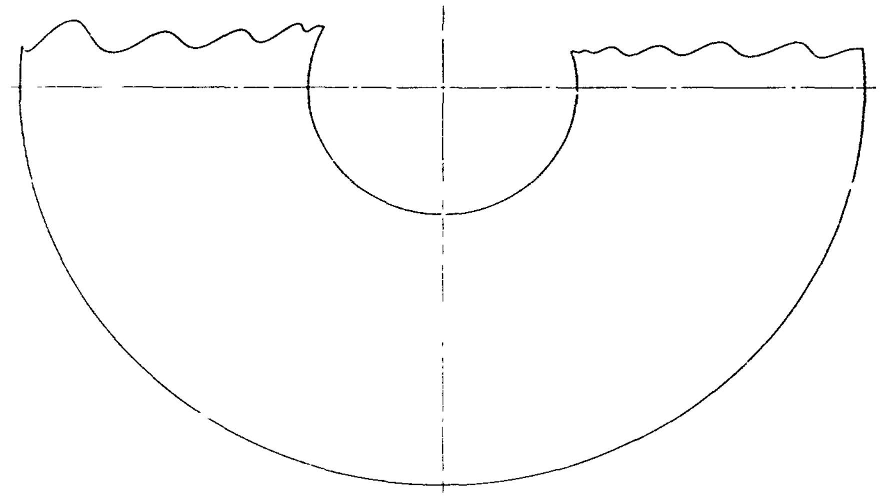
Thiokol CHEMICAL CORPORATION
WASATCH DIVISION BRIGHAM CITY UTAH

INSULATION, THERMAL, AFT CASE

07703 | J | 9U34069

Figure 31. TU-290 Motor Revised Aft Case Insulation Drawing 9U34069





BASIC COORDINATE TABLE SURFACE A		BASIC COORDINATE TABLE SURFACE B	
X	Y	X	Y
-.0028	21.9269	-.0042	21.8869
+.5948	21.9070	+.5922	21.8668
.9911	21.8544	.9066	21.8197
1.5872	21.7752	1.5805	21.7515
1.9846	21.7025	1.9764	21.6602
2.5515	21.6180	2.5720	21.5748
2.9780	2 .649	2.9655	21.4205
3.5740	21.2792	3.5585	21.2529
3.9715	21.1567	3.9535	21.0891
4.5687	20.9789	4.5485	20.9299
4.9647	20.7120	4.9402	20.6608
5.5621	20.5133	5.5346	20.4605
5.95[illegible]	20.1821	5.9256	20.1670
6.5541	19.8087	6.5159	19.7510
6.9514	19.5347	6.9090	19.4754
7.5486	19.2592	7.5018	19.1782
7.9447	18.7626	7.8901	18.6892
8.5406	18.2089	8.4774	18.1492
8.9378	17.8112	8.8682	17.7441
9.5349	17.3825	9.2584	17.3139
9.9305	16.6754	9.8426	16.6035
10.5257	15.8741	10.4248	15.8092
10.7240	15.5846	10.6184	15.5134
10.9223	15.2824	10.8118	15.2111
11.1205	14.9665	11.0049	14.8952
11.3185	4.6961	11.1976	14.5648
11.5165	14.2901	11.3901	14.2109
11.7145	13.9273	11.5821	13.8565
11.9119	13.5465	11.7735	13.4757
12.1093	13.1466	11.9646	13.0762
12.3064	12.7261	12.1551	12.6560
12.5030	12.2842	12.3449	12.2145
12.6991	11.8200	12.5359	11.7505
12.8943	11.3338	12.7219	11.2643
13.0882	10.8274	12.9085	10.7574
13.2800	10.3061	13.0932	10.2946
13.9450	8.5000	13.3494	7.0000
13.4270	8.5000		
13.5494	7.0000		

NOTES:

1. GENERAL TIRE & RUBBER CO., AKRON, OHIO.
2. CONTOURS OF SURFACES A & B MAY VARY WITHIN A .020 TOLERANCE BAND PARALLEL TO ℄ CENTERED ON BASIC.
3. THESE COORDINATES FORM A STRAIGHT LINE.
4. MARK PART NO. PER TUS-59-33, METHOD 6.

QTY	ITEM NO.	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
			-01	INSULATION	V-44	1

LIST OF MATERIAL OR PARTS LIST

Thiokol CHEMICAL CORPORATION
WASATCH DIVISION BRIGHAM CITY UTAH

LINER, INSULATING, HEAD END

07703 J 9U34070

NEXT ASSEMBLY 9U34071

Figure 32. TU-290 Motor Head End Insulating Liner Drawing 9U34070

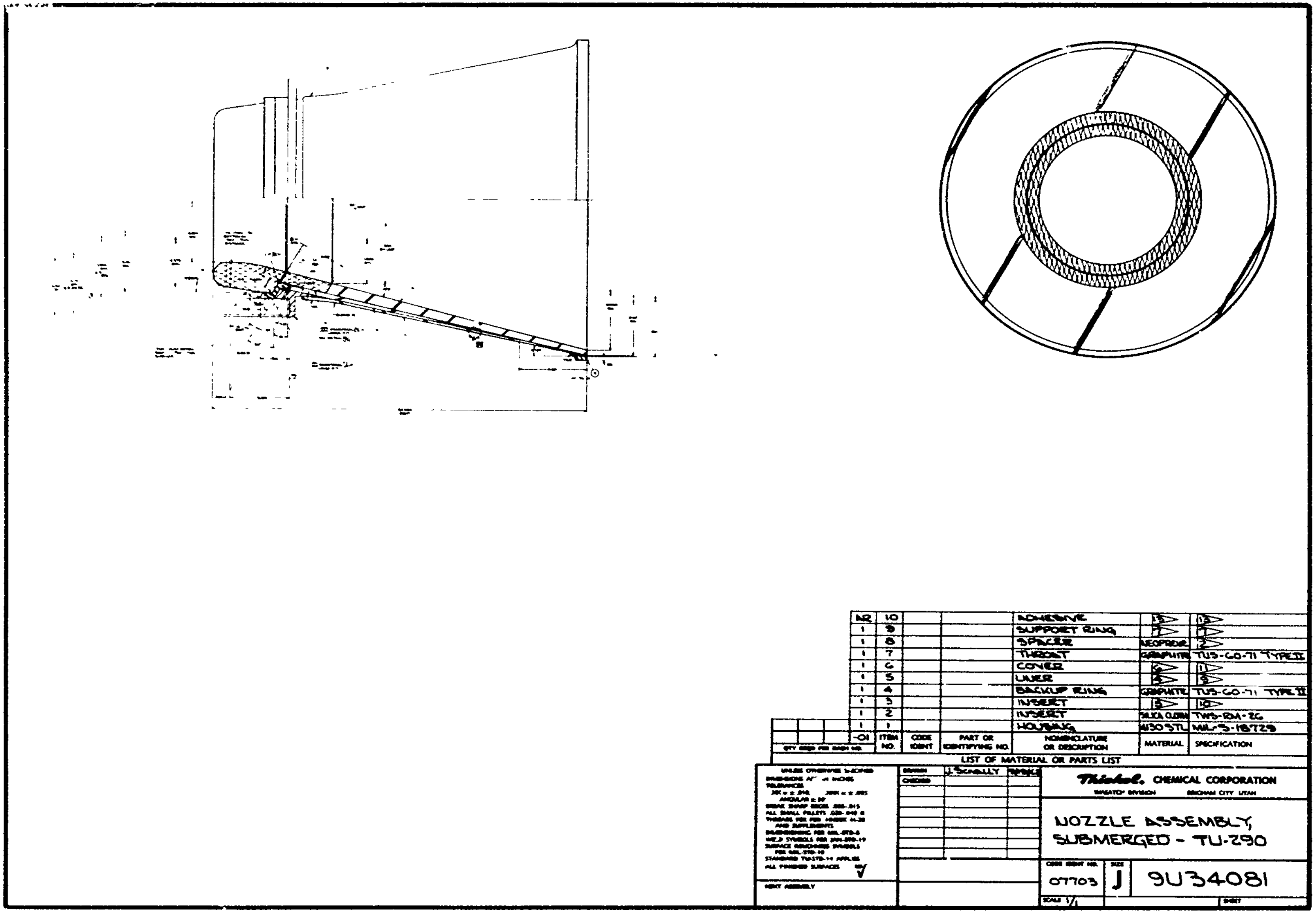


Figure 33. Preliminary TU-290 Nozzle Design Drawing 9U34081 (Page 1 of 2)

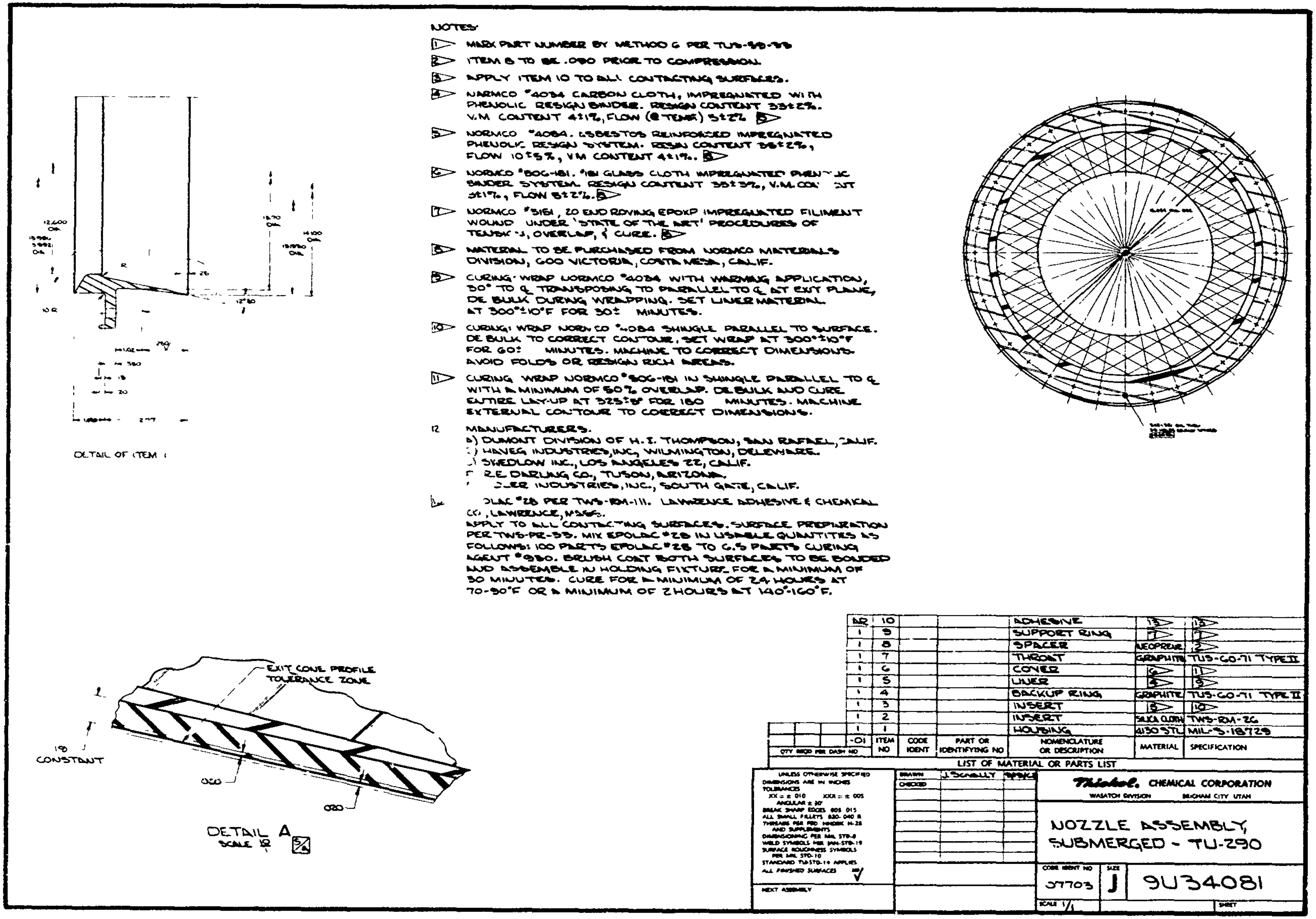


Figure 33. Preliminary TU-290 Nozzle Design Drawing 9U34081 (Page 2 of 2)

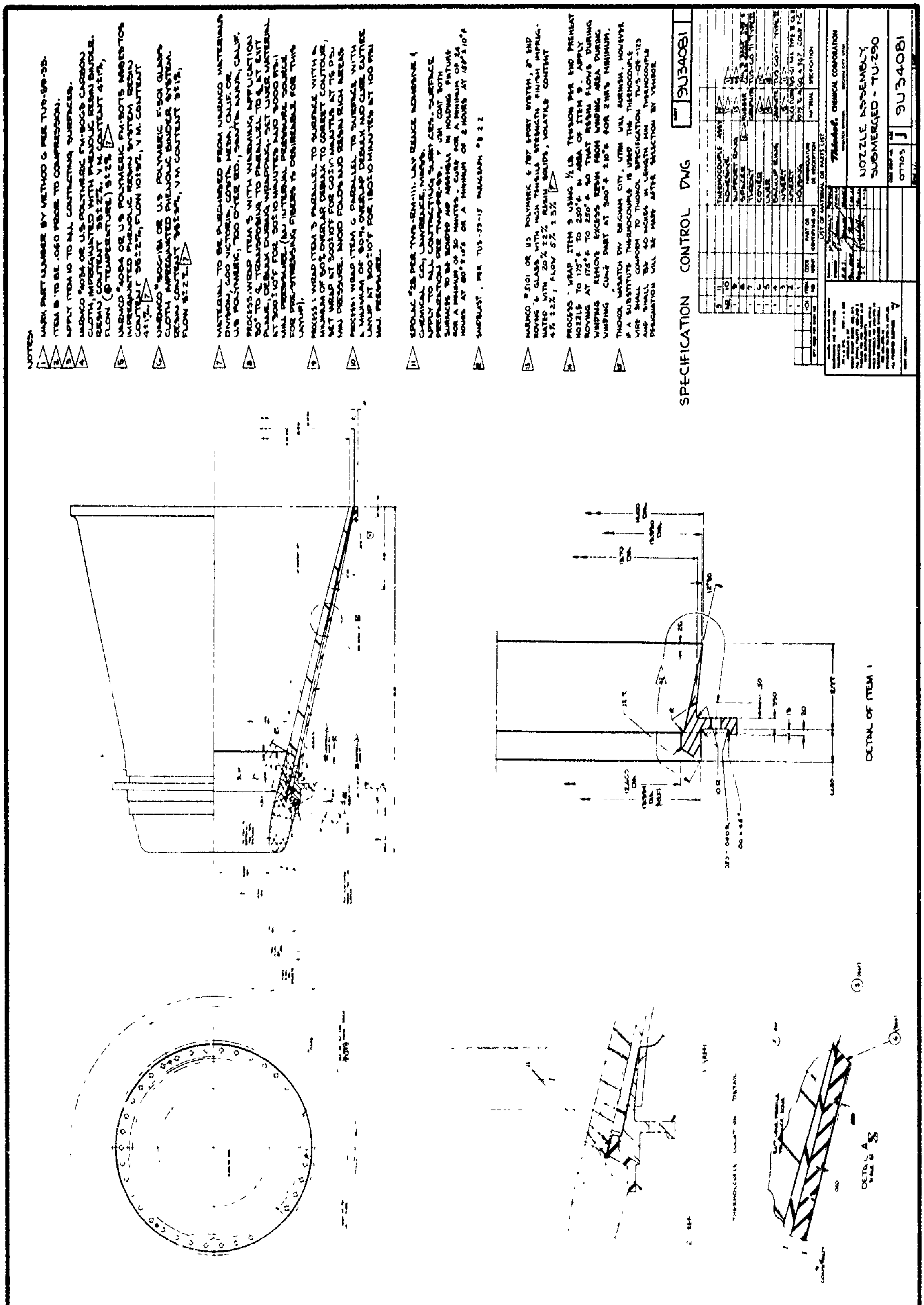


Figure 34. TU-290 Nozzle Design Drawing 9U34081

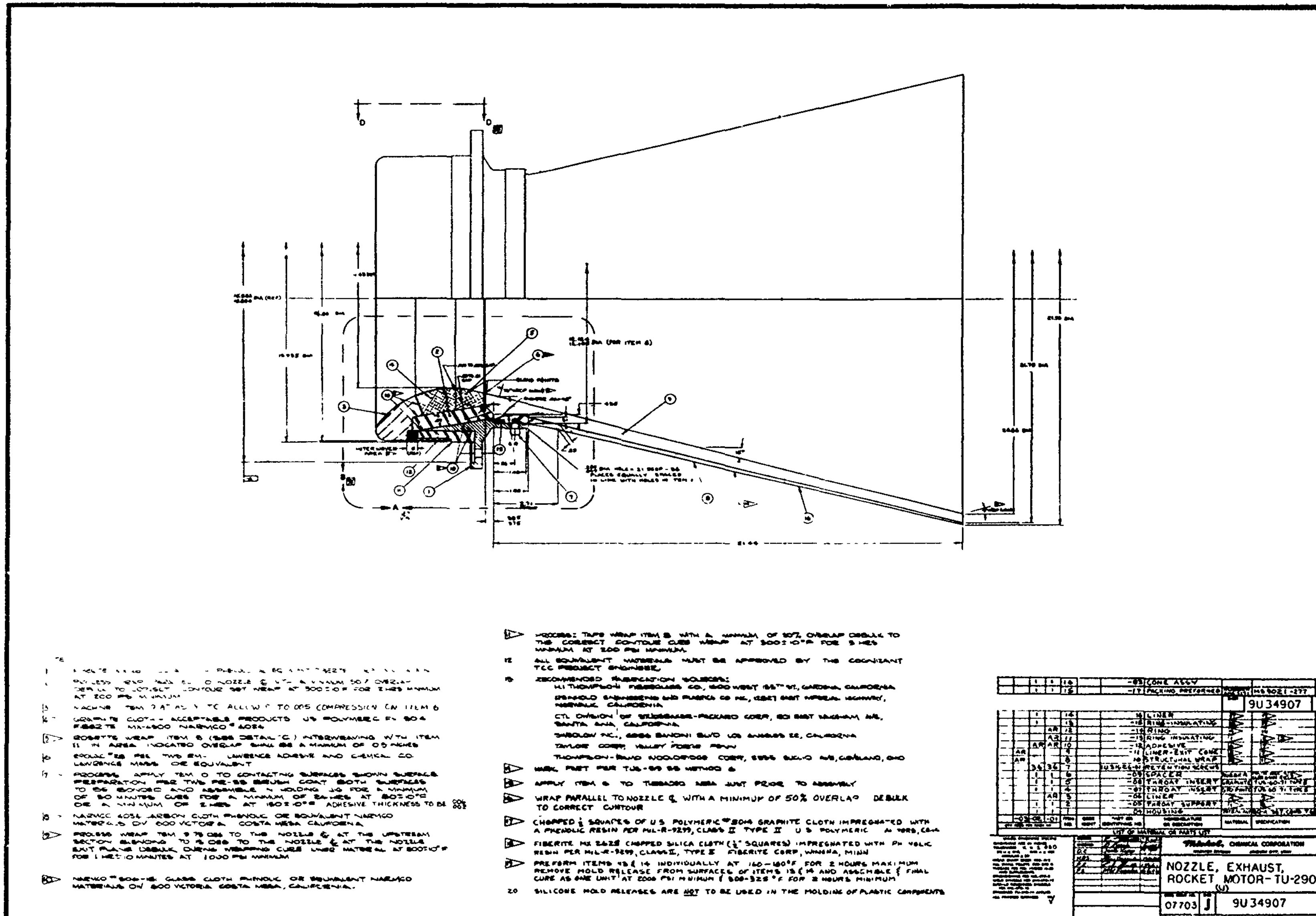


Figure 35. TU-290 Nozzle Design Drawing 9U34907 (Page 1 of 3)

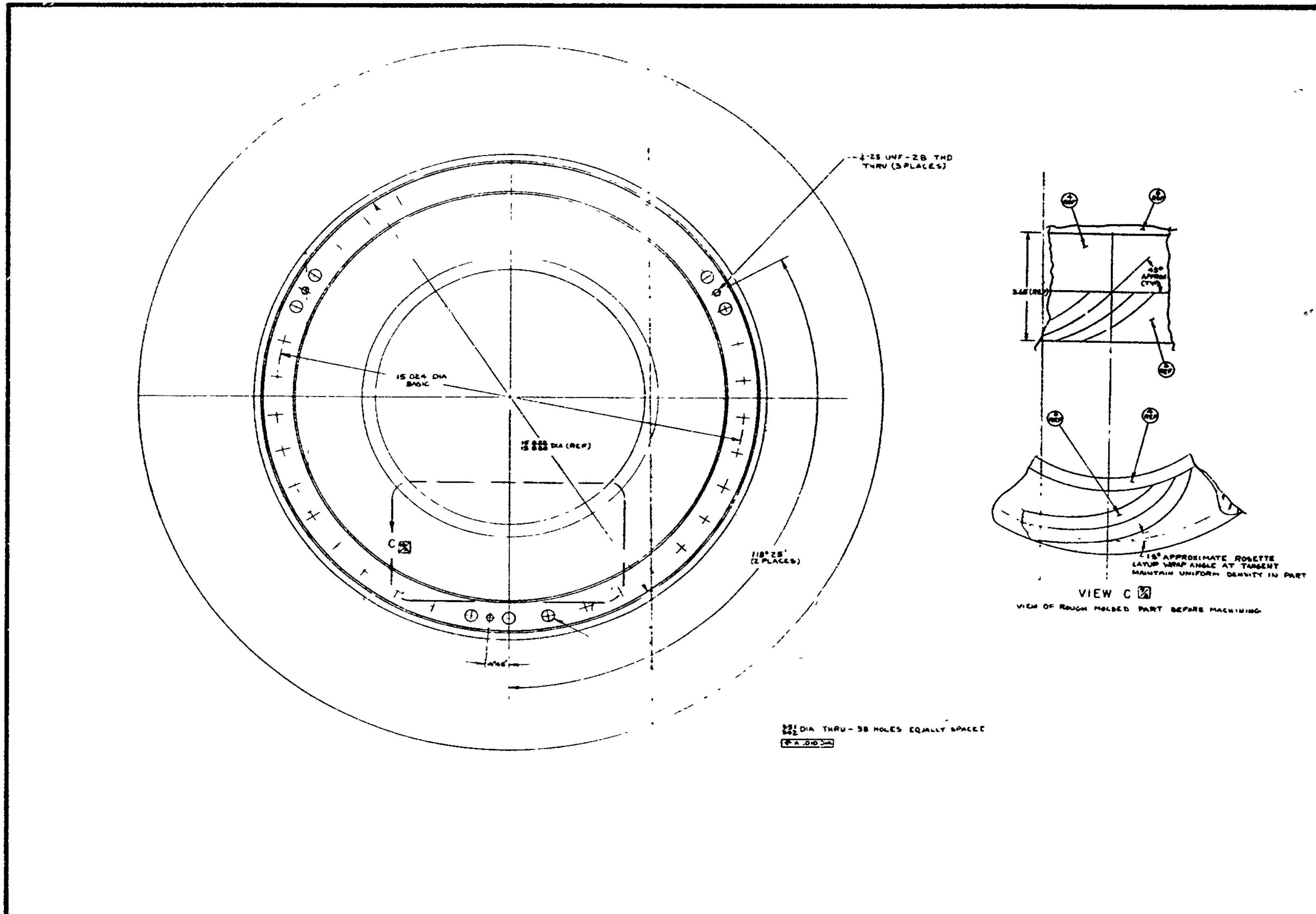


Figure 35. TU-290 Nozzle Design Drawing 9U34907 (Page 2 of 3)

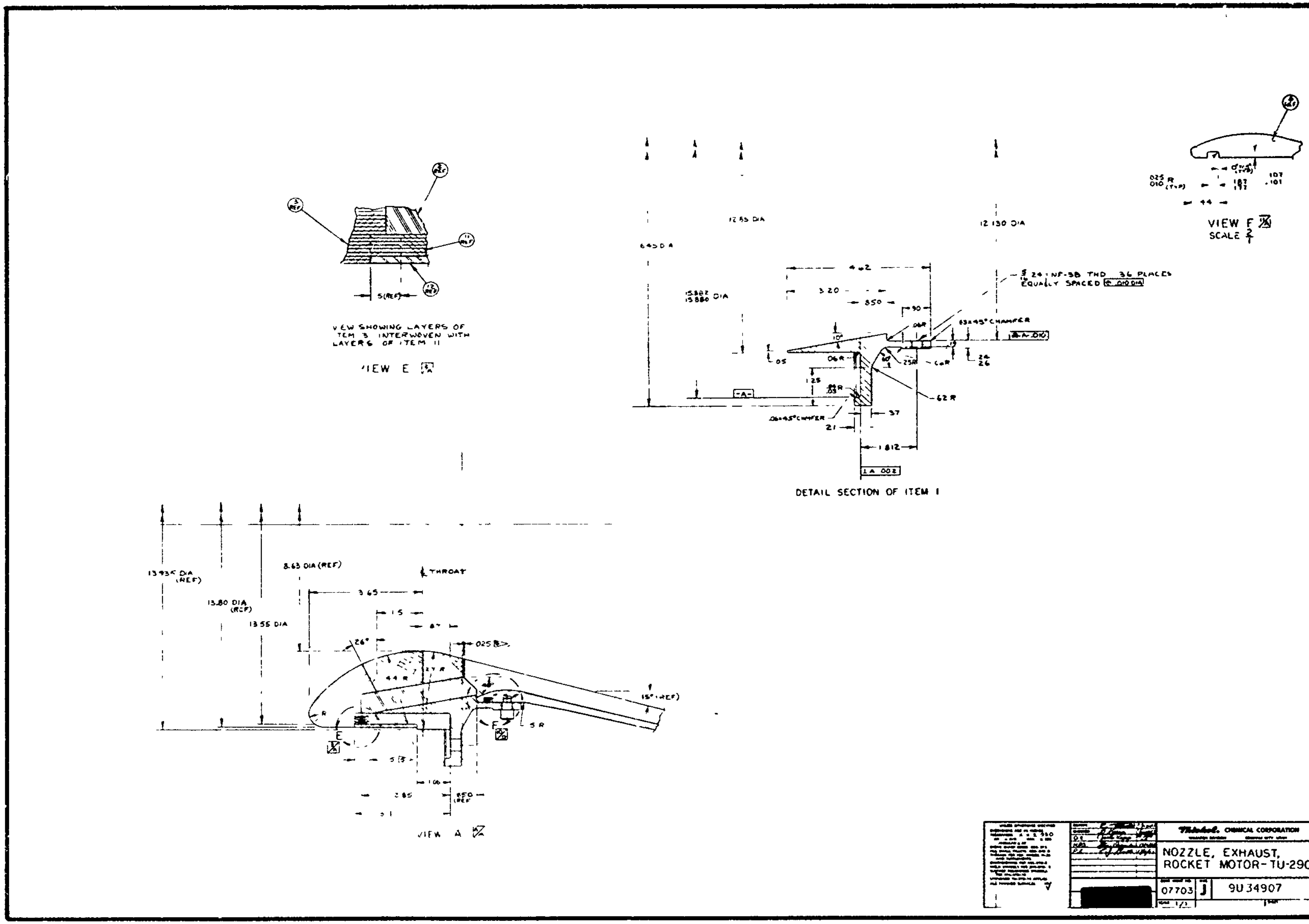


Figure 35. TU-290 Nozzle Design Drawing 9U34907 (Page 3 of 3)

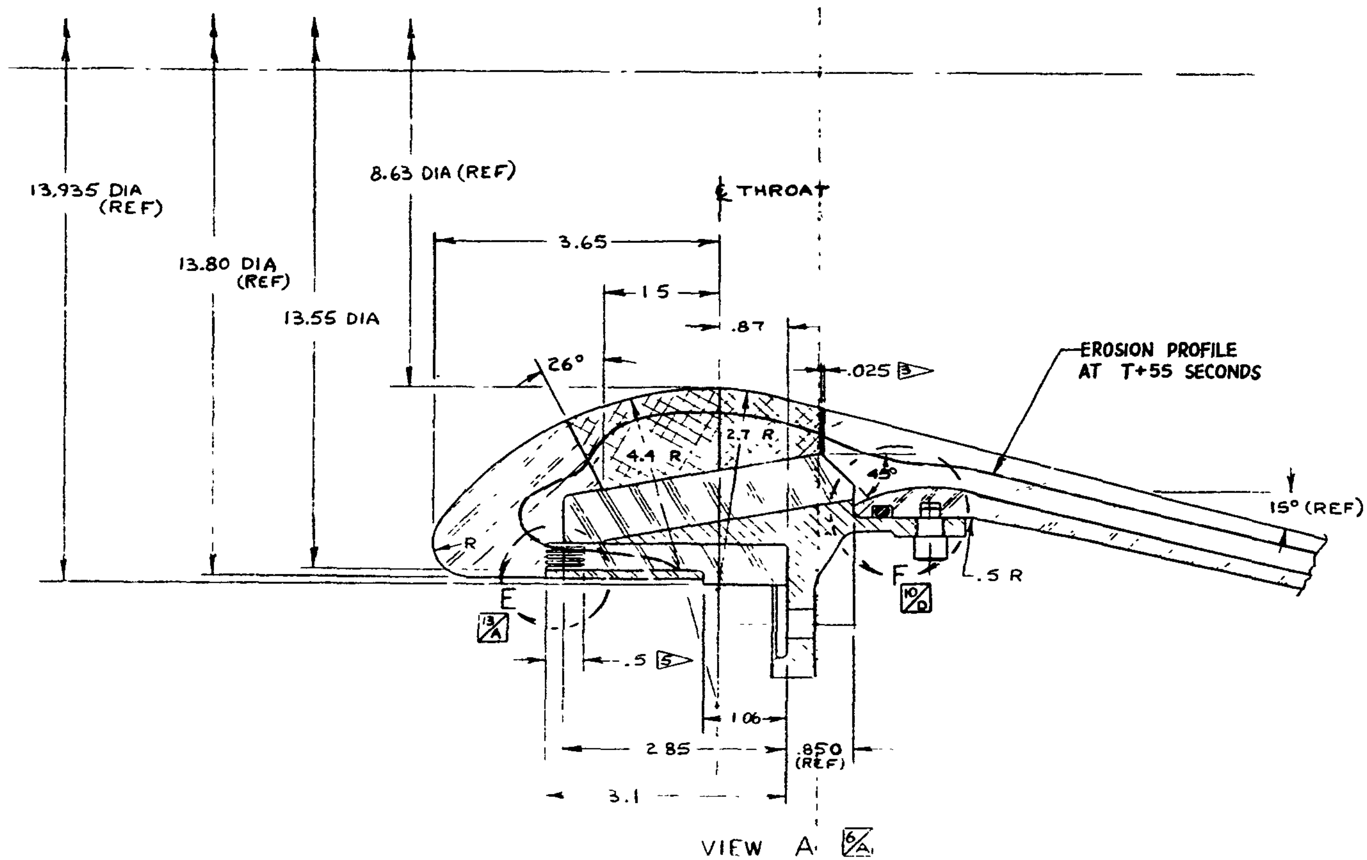


Figure 36. Nozzle Erosion Profile - Drawing 9U34907

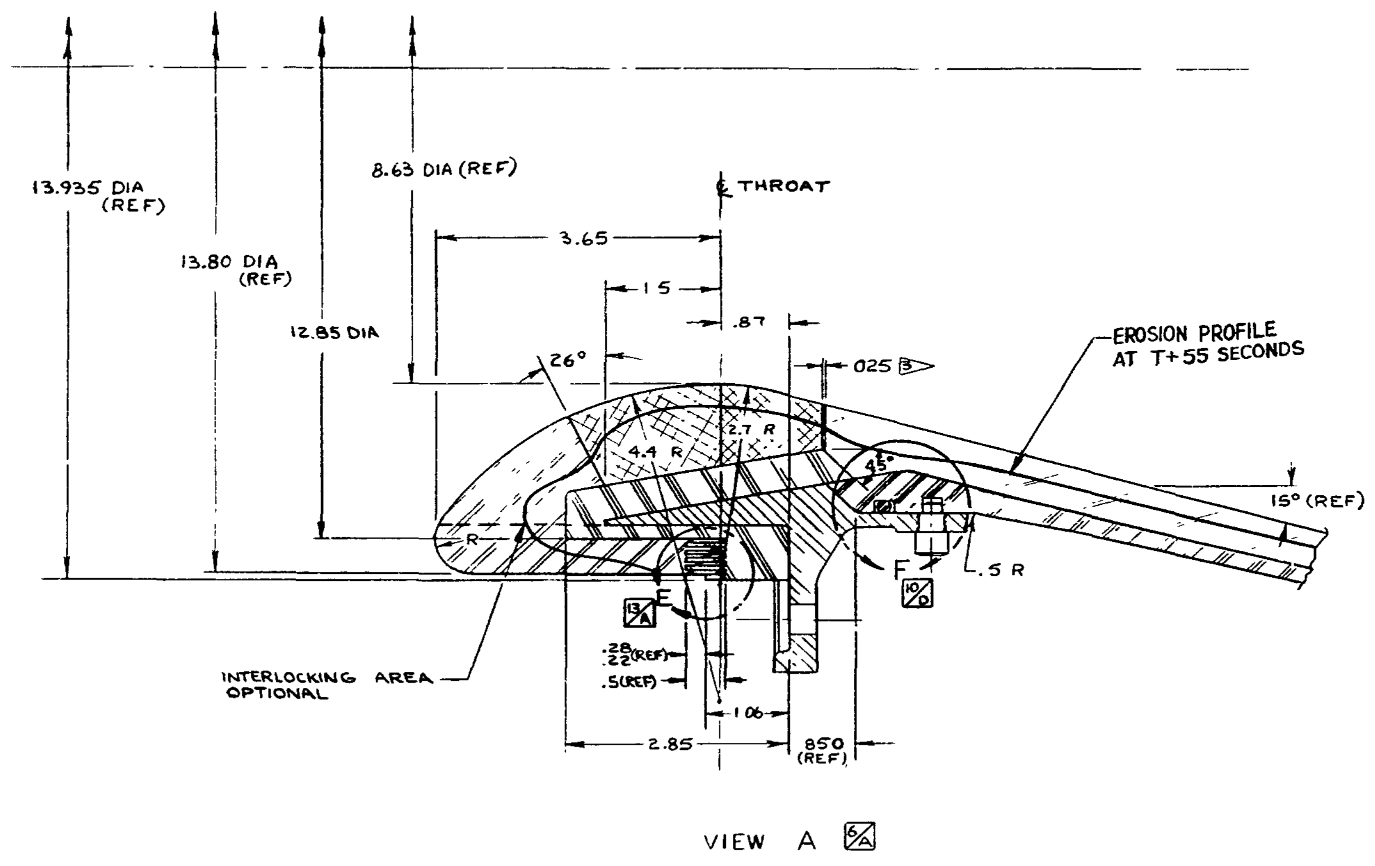


Figure 37. Nozzle Modification to Drawing 9U34907

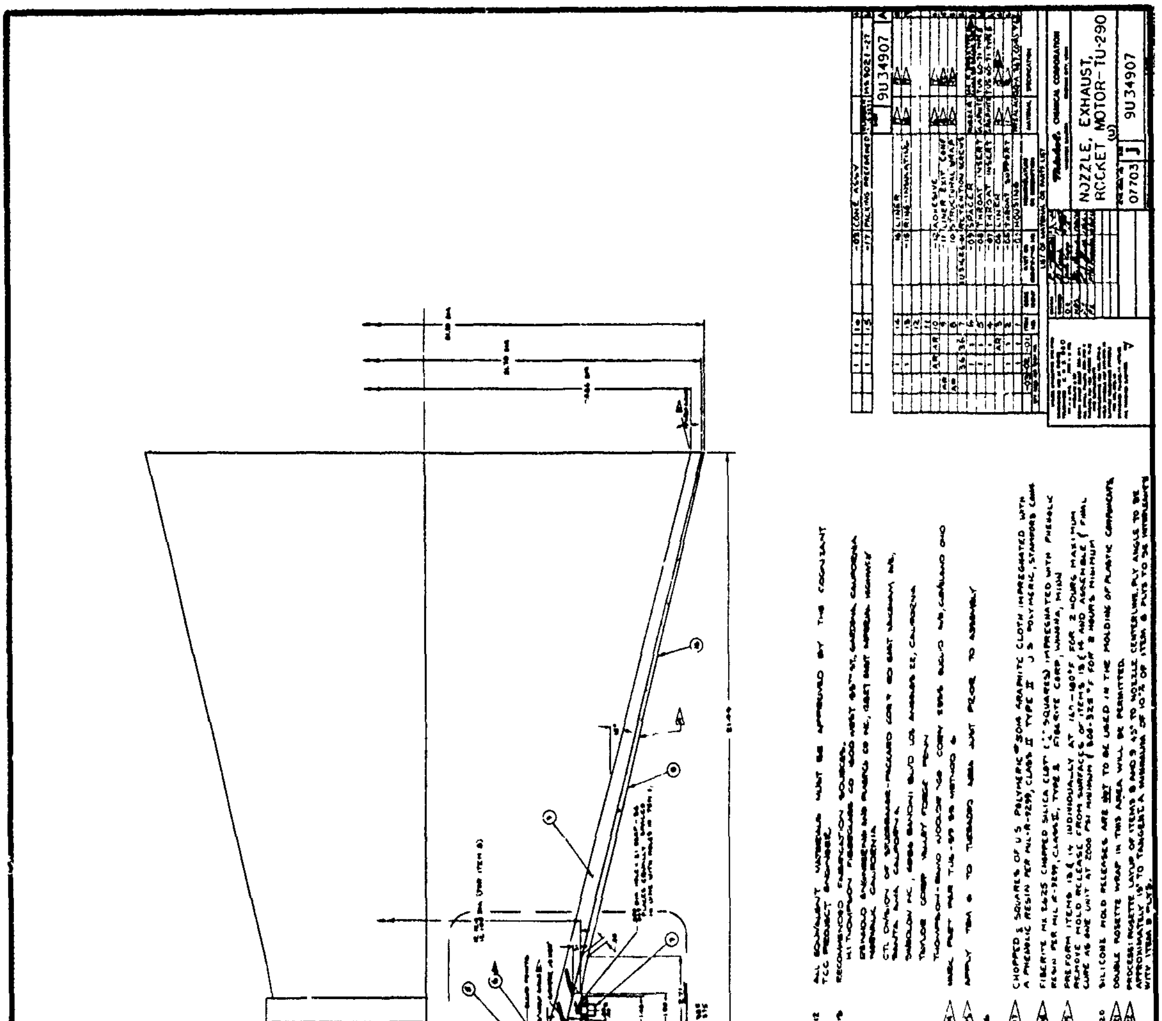


Figure 38. TU-290 Nozzle Design Drawing 9U34907A (Page 1 of 3)

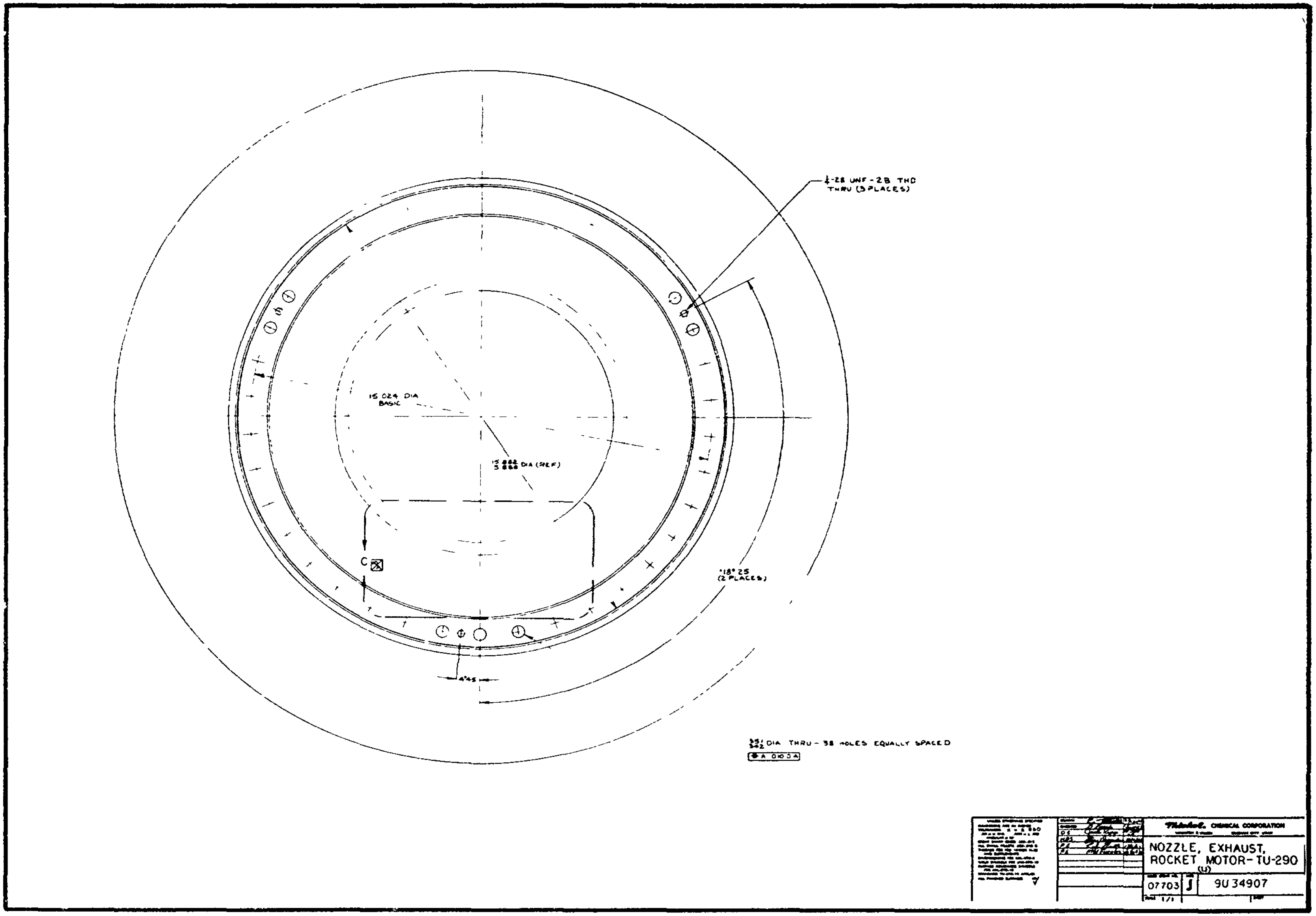


Figure 38. TU-290 Nozzle Design Drawing 9U34907A (Page 2 of 3)

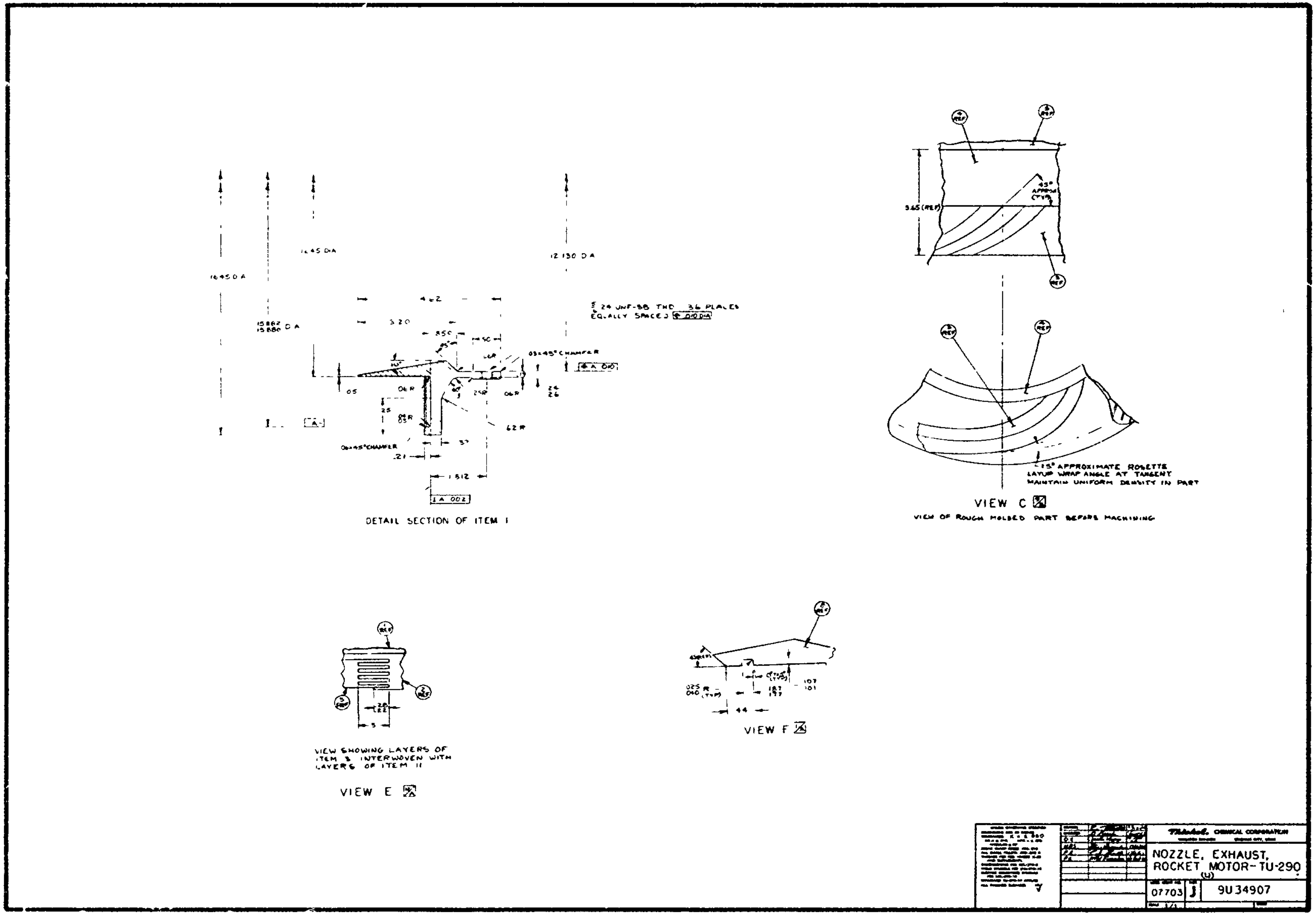


Figure 38. TU-290 Nozzle Design Drawing 9U34907A (Page 3 of 3)